PETROLOGY

OF THE

FRANCOIS RIVER GABBRO

BY

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A PETROGRAPHICAL STUDY OF GABBRO-LIKE PRECAMBRIAN ROCK TYPES IN THE FRANCOIS RIVER DISTRICT, GREAT SLAVE LAKE, N.W.T.

by

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A THESIS

Submitted to the University of Alberta in partial fulfilment of the requirements for the degree of Master of Science. This major thesis represents approximately three-quarters of the work of an academic year and an additional three months in the field.

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INTRODUCTION

General Statement and Acknowledgements.

In the summer of 1935 the Geological Survey of Canada, as part of an extended program of field work, sent many parties into areas not previously examined. The writer was attached to a party under the direction of Dr. F. Jolliffe, which mapped the Yellowknife River area, that covered about 10,000 square miles of territory lying north of the north and east arms of Great Slave lake. An important result of this work was the discovery of some 3000 square miles of metamorphosed early Precambrian sediments which are considered to be favorable ground for prospecting. One of the most interesting fields of study was the body of gabbro-like rocks in the Francois River district. The variation of rock types in and around this body of gabbro, from metamorphosed greywackes, or from granites to anorthosite, or to banded segregations of magnetite, and banded gabbros showing stratiform differentiation made it an intensely interesting area.

During the time spent in study of the gabbro the

writer collected specimens for microscopic examination. He is greatly indebted to Dr. Jolliffe, who made it possible for him to undertake this study, and who gave generously of his time and advice both in the field and at later times. In the laboratory, the advice of Dr. J. A. Allan and of Dr. R. L. Rutherford and the guidance of the latter in the microscopical work are gratefully acknowledged. Dr. A. E. Cameron gave generous assistance and advice in the study of a polished section of magnetite. The laboratory work in connection with the study of this problem was made possible through a University of Alberta Research Scholarship for the award of which the writer wishes to thank the Board of Governors of the University.

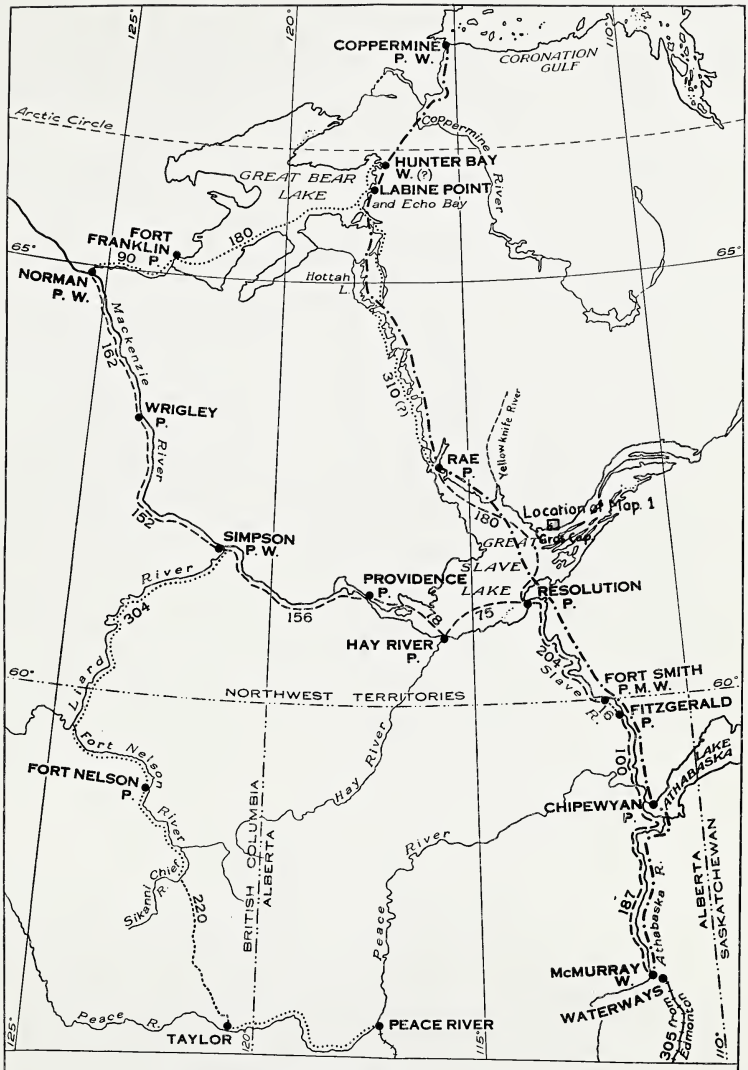
Location and Means of Access.

The Francois river is one of a number of minor streams flowing into the northeast portion of Great Slave lake from the north. By air it is about 115 miles southeast of Fort Rae and 20 miles east of Gros Cap, which is a prominent landmark in this section of the lake. These geographical relationships are shown in plate 1, which also indicates the main routes of travel in the north. The gabbro body is situated

EXPLANATION OF PLATE 1

Index map showing routes of travel in the north, and the location of the Francois River district.

PLATE I



ROUTES TO

GREAT BEAR LAKE AND NORMAN

NORTHWEST TERRITORIES

Scale of Miles

100 50 0 100 200

- Main aircraft route
- Summer steamer route
- Boat, scow, or canoe route
- Portage
- Railway
- P. Trading post
- M. Mining recording office
- W. Wireless or telegraph
- 152 Approximate distance in miles between points

Geological Survey, Department of Mines, Canada, 1932.

Publication No. 2301

some 1 1/2 miles north of Great Slave lake and 2 miles east of Francois river.

Access to the area is by boat in the summer months, and by air all year. Details of the routes of travel to Great Slave lake are given by Kidd and Stockwell (1). The following notes bring this information up to date and deal specifically with that relevant to the district about the gabbro.

The nearest regular port of call for the boats plying on Great Slave lake is the camp of the Burwash Yellowknife Mines, 50 miles northwest. The routes of travel, however, all lead past Gros Cap (pl. 1). The Canadian Airways in January 1935 transferred its radio station and refuelling base from Fort Rae to the Burwash camp which is now on the air route to Great Bear lake.

Francois bay, two miles west of the gabbro area, provides a good harbor. The gabbro body may be reached overland from Great Slave lake or by following an Indian canoe route which reaches Bird lake (map 1) by way of Caribou lake. Numerous lakes within the gabbro

(1) Kidd, D.F., Geol. Surv., Canada, Sum. Rept. 1931, part C, pp. 47c - 49c.
Stockwell, C.H., Geol. Surv., Canada, Sum. Rept. 1932, part C, pp. 38c - 39c.

provide fair landing for aircraft, landings having been made during the season of 1935 on Bird, White Man, Caribou, and Mad lakes.

Previous Work.

The Great Slave Lake area was examined by Robert Bell in 1899 (1). His work was exploratory and no mention of the gabbro was made, probably because of the fringe of granite along the shore. It is interesting to note that he recognized the existence of the large area of sediments whose boundaries were delineated in 1935 by the Yellowknife party, although it is not evident how he ascertained its presence.

C. H. Stockwell carried out field work in this area in the summers of 1929 to 1932. His work was confined to shoreline and canoe route reconnaissance, but as a consequence of the discovery of nickel in the gabbro by Paul Beaulieu in 1932, he made a brief examination of the gabbro, the results of which are to be found on pp. 55c and 60c-61c of his report (2).

The gabbro body was visited by J. Barrington, Ventures geologist, some time subsequent to the nickel discovery, and a copy of his sketch map, supplied to

(1) Bell, Robert, Geol. Surv., Canada, Ann. Rept., vol. xii, part A, pp. 103-110, 1899.
(2) Stockwell, C.H., Op. cit.

the party by Mr. A. Cameron of Ventures, gave much valuable information concerning the topography and surface geology of the body.

The general geology of the area, as worked out in the field in 1935 is briefly dealt with in the "Preliminary Report on the Yellowknife River Area, Northwest Territories", 1936, paper 36-5 of the Geological Survey of Canada.

Physical Features and Climate of the Region.

The district forms a part of the Precambrian shield, and the physiographical descriptions so familiar to students of Precambrian geology would in general apply well here. The country is rugged and rocky, with narrow valleys and round flat-topped hills with steep slopes. The depressions are occupied by lakes and muskegs which are underlain with glacial drift.

It was found that, contrary to the usual generalization, the surrounding granite was characterized by low comparatively flat, muskeg-covered stretches, while a more rugged topography marks the gabbro body, although a grey granite stock which was the most prominent landmark in the vicinity was an exception (pl. 2).

The country has been ravaged by forest fires at

PLATE 2

EXPLANATION OF PLATE 2

Aerial photograph of eastern portion of the gabbro body, looking southeast. The contact of the granite and gabbro, as shown by a more rugged topography in the latter, is evident. White Man lake is in the foreground. The arrows show the contact.

(Royal Canadian Air Force photograph)

PLATE 2

least twice in the past quarter century. As a consequence windfalls of burnt timber make travel over the gabbro body difficult (pl. 3A). Another consequence due probably to these fires, is the weathered nature of the rocks,(1). The gabbros and related rocks, and to a lesser degree the more resistant granites in the vicinity, often have a covering of disintegrated, incoherent rock, made up of more or less weathered individual crystals (pl.13A).

Atmospheric erosion seems to have been more intense in the gabbro than elsewhere in the district, for polished surfaces, striae, and other evidences of glaciation were not noted on its surface, although common enough in other rocks. Thus fresh specimens were at all times extremely difficult and in some cases impossible to obtain. Much of the gabbro suffered alteration when the granite was intruded, and therefore the difficulty of obtaining specimens which were at least free from the effects of weathering is particularly unfortunate.

(1) Blackwelder, E., Fire as an agent in rock weathering, Jour. Geology, vol. 35, pp. 134-140, 1927.

GENERAL GEOLOGY AND PETROLOGY

RELATIONSHIPS OF THE ROCKS IN THE AREA.

The formations occurring in the immediate vicinity of the gabbro body may be grouped as follows:

TABLE OF FORMATIONS

QUATERNARY	Glacial drift, sand beaches.
Great unconformity.	
PRECAMBRIAN	Diabase dikes.
	Intrusive contact.
	Granite, granodiorite.
	Intrusive contact.
	Gabbro, anorthosite, pyroxenite, etc.
	Intrusive contact.
	Metamorphosed sediments, greywacke, slate, etc.

The oldest rocks of the district consist of highly metamorphosed sediments, which as a broad belt occupy the basins of the Francois and Beaulieu rivers, (1). These rocks are for the most part fine-grained, arkosic greywackes, interbedded with slates and argillites. The weathered surface of these rocks varies in color from grey-green to rusty brown, and shows well-marked banding, individual bands ranging from one thirty-second of an inch to three or four feet. On the fresh surface, the rocks are chiefly fine-grained, grey-green to silvery grey chlorite and mica schists, which show no trace of the bedding apparent on the weathered surface.

Much of the sedimentary rock in the district shows nodules up to two inches long, which sometimes stand out on the weathered surface, or sometimes are eroded inward, giving the rock a knotted appearance suggesting conglomerate. These nodules are metacrysts or centres of growth of chiastolite and similar metamorphic minerals. Some seem to be aggregates of crystals but in a few places crystal units showed well the characteristic orientated inclusions of chiastolite.

(1) See map accompanying G.S.C. paper 36-5, "Preliminary Report on the Yellowknife River Area, N.W.T.", 1936.

A particularly good outcrop of the nodular weathering rock near the gabbro body occurs on the islands in Francois bay, in the vicinity of the Indian cabins. These rocks form a part of the assemblage of sediments and volcanics termed the Point Lake-Wilson Island series by Stockwell,(1) who places them in the Early? Precambrian.

The gabbro-anorthosite complex which is the subject of this thesis is summarized at the conclusion.

The granites of this area have never been studied in detail and may consist of several petrographical types. Stockwell (2) states "these intrusive granites north of Great Slave Lake are of two main types. One is red and is granodiorite in mineral composition. Its feldspars are oligoclase and microcline in about equal proportions and the rock carries biotite or muscovite and, at many places, feldspar phenocrysts... Within the main areas of these red granodiorites are small areas of gneissic, red, massive, light grey, white, and pink, and slightly gneissic, dark grey granites... The other main type of granite north of Great Slave Lake is a light grey to white rock varying in mineral composition at different localities." These range from microcline-biotite and muscovite granite to biotite-oligoclase-

(1) Stockwell, C.H., Op. cit., p. 46c,
(2) ----------, Op. cit., p. 53c.

quartz diorite. Specific descriptions of granite thin sections follow later in this section.

In the Francois River district contacts are for the most part sharp. Elsewhere in the area, however, a contact zone several miles wide, grading from pegmatitic granite, or hybrid granite, through injection gneiss and lit-par-lit sills to sediments cut by pegmatite dikes often occurs. A few examples of hybrid rocks were noted within the gabbro.

All the rocks are cut by the ubiquitous diabase dikes and sills. These are definitely late Precambrian, since they cut the Et-Then series, Athabasca sandstone in age, on Et-Then island to the east of the gabbro body.

DISTRIBUTION OF THE GABBRO-LIKE ROCKS.

Map 1 shows the gabbro body to be in plan somewhat oblong. The gabbro mass is bounded by granite on all sides with the exception of the north where it is in contact with sedimentary rocks. The position of the contacts as mapped is approximate, since no accurate map was available and the presence of bodies of magnetite hindered the pace and compass surveying methods employed. Moreover the actual contacts were practically all drift covered.

In the southern and southeastern ends of the gabbro body it appears that the contact of the bottom of the gabbro with the granite is at a relatively high elevation, with the result that there the higher hills are capped with gabbroic rocks while the lower ground is granite. The effect of this on the position of the contacts is obvious but cannot be mapped without some form of instrumental survey. After determining by traverse the physiographical relationship noted on page 5, the contact from this point to Mad lake was determined accurately from aerial photographs, (see pl. 2). (The topographical base for the map was prepared by the writer from aerial photographs kindly loaned by Dr. Jolliffe).

In the short time and with the mapping methods at the disposal of the field party it was not possible to map the individual rock types in the field.

The exposed area of the gabbro is about 13 square miles.

PETROLOGY OF THE FRANCOIS RIVER GABBRO

PETROLOGY OF THE MAIN ROCK TYPES

The rocks of the gabbro are divided into two broad types, namely, anorthosites and gabbros. There are in addition two subordinate masses of ultrabasic rock, and some hybrid types due to the assimilation of sedimentary rocks by the gabbro, and of both sediments and gabbro by the granite.

Gabbroic Rocks.

The gabbroic rocks include several varieties. Peridotites, dunites, and other ultrabasic rocks were not found in the gabbro, although in some places the feldspar made up only 30 percent of the rock, (see slide A144). There is a possibility that in places, particularly in the lower portions of the outcrop at sta. A138, such rocks might be present. There a coarse sand occurs made up of rusty decomposed rock up to six or eight inches thick, grading into decomposed rock in place. The resistance of the ultrabasic portions of gabbroic bodies to weathering is elsewhere found to be poor.

Rocks that appear to be amphibolites occur at two localities apart from the gabbro. On an island in the southwest portion of Francois bay (sta. F8),

a dark green, fairly homogeneous amphibolite showing generally coarse grains of amphibole having cleavage faces over one inch across occurs. The whole island is made up of this rock. On the Francois river (at sta. F190) a similar rock was found which showed a few streaks of chalky altered feldspar. The rock formed a topographical eminence, standing about seventy-five feet above the bed of the stream, and although its contacts were drift masked, seemed to have the form of a small stock.

The normal gabbroic types include rocks whose ferromagnesian minerals are olivine, augite, and hornblende. Of nine gabbro slides examined, four contain olivine, and eight contain augite or strong evidence of the former presence of a pyroxene. Five contain augite with secondary hornblende, suggesting that in the two which carry hornblende alone it is secondary to augite.

The feldspars crystallized early and the gabbros for the most part show a diabasic or ophitic texture. They are on the whole coarse grained, and Dr. Jolliffe coined the term "megalophitic" for the occurrence of this texture on a megascopic scale (see plate 3B).

On the basis of grain size two varieties of the gabbros may be distinguished, the normal gabbro with a grain up to a quarter of an inch, and the pegmatitic

EXPLANATION OF PLATE 3

A. Windfalls of burnt timber make travel over the gabbro difficult in many places.

B. Megalophitic, or coarse diabasic, texture shown on the weathered surface of a hand specimen of gabbro. Natural size.

PLATE 3

A

B

type, often showing megalophitic texture, with coarse grain up to 1 1/2 inches, and consisting of the same minerals as the normal gabbro with the possible substitution of hornblende for pyroxene. The pegmatitic type is believed to represent concentrations of mineralizers, water, sulphur, etc., along certain bands and in certain spots in the gabbro (1).

The feldspar of the gabbro is in general basic labradorite and acid bytownite, although as acid a plagioclase as $Ab_{43}An_{57}$ and as basic as $Ab_{15}An_{85}$ occur. This range may be explainable by the intrusion of the granite. The feldspars on the whole are highly altered. The commonest alteration products are clinozoisite and calcite, but in one or two places sericite-like products were observed.

The augite of the gabbro is in thin section colorless to a vary faint purplish red, only faintly pleochroic, although in one place (slide A144) it is titaniferous augite, and has yellowish to purple brown pleochroism. The augite is full of microscopic orientated needles and rods of a dark mineral (see pl. 4A), forming schiller structure. This mineral is probably ilmenite or titaniferous magnetite, this conclusion

(1) Grout, F.F., The pegmatites of the Duluth gabbro, Econ. Geology, vol. 13, 1918, pp. 185 -197

being borne out by the facts that where iron stain is found in the augite it is comparatively free from inclusions, and that no inclusions occur in the titaniferous augite. The augite of the gabbro is often altered to secondary hornblende and to chlorite, biotite, and iron oxide.

Olivine is present in four slides. It is an iron-rich variety, being optically negative in all cases, therefore contains over 13 percent FeO. The maximum birefringence observed in a slide of normal thickness indicates an iron content of at least 26 percent FeO. It commonly alters to the non-fibrous variety of serpentine, antigorite, and iron oxides, the latter occasionally paralleling the cleavage. In one slide a zone of serpentine (antigorite) was surrounded by a zone of magnetite and this by a zone of leucoxene and calcite. The olivine shows no reaction rims of augite, garnet, hornblende, and the like, as described by Sederholm and Gillson (1).

(1) Sederholm, J.J., On synantectic minerals, Bull. Comm. Geol. de Finlande, N:o 48, 1916
Gillson, J.L., Callahan, W.H., and Millar, W.B., Adirondack Studies: The age of certain of the Adirondack gabbros, and the origin of the reaction rims and peculiar border phases found in them, Journ.Geology, vol. 36, 1928, pp. 149-163.

Titaniferous magnetite is one of the most abundant accessory minerals in the gabbros, which contain from five to ten percent of this mineral. It commonly occurs as irregular grains interstitial to the plagioclase laths, in some cases giving the rock a texture which has been called sideronitic (1) (see pl. 4B). The titaniferous magnetite alters to a yellowish opaque mineral, probably leucoxene. Concentrations of magnetite occur in pegmatitic patches, and in one place as a band in the gabbro.

Irregular grains of yellow sulphides, determined in the hand specimen as both pyrite and chalcopyrite, commonly occur in association with the magnetite.

Biotite, while in some cases primary, is for the most part a reaction product of the ferromagnesians and ores with the plagioclase. In the reaction rims it generally occurs as flakes with ragged outlines surrounded by a vermicular intergrowth of hornblende, largely chloritized, and plagioclase feldspar. The biotite may form part of the vermicular intergrowth. Such a texture has been termed by Sederholm (2), a hornblende-biotite symplectite.

(1) Osborne, F.F., Magmatic titaniferous iron ores, Econ. Geology, vol. 23, 1928, p. 757.
(2) Sederholm, J.J., Op. cit., p. 46.

Titanite occurs in three of the slides. In some places it seems primary but in others its close association with the pyrite and magnetite and the absence of typical wedge-shaped grains suggest that it is secondary.

The first mineral to crystallize in the gabbro, apart from the apatite, was the plagioclase. Following this olivine, augite, and magnetite began to crystallize. The olivine preceded the other ferromagnesians. The magnetite asserts its crystal outlines against the augite and is moulded on it, suggesting that cessation of crystallization of these two minerals was in part contemporaneous.

Reaction rims are common in the gabbro. Although these are not all found about the one mineral the sequence is apparently:
pyroxene (augite)→ amphibole (hornblende)→biotite.
Much of the pyroxene has gone over to a green hornblende, uralite, (see pl. 5A). Another common series is:
magnetite or chalcopyrite→biotite→hornblende ,
the last-named mineral being found intergrown with the plagioclase as a symplectite. There are two main causes for such structures, primary magmatic reaction, and secondary, paulopost magmatic reaction or the action of

metamorphism. Both have probably been active in the gabbro but to distinguish between the two has not been possible, so the term 'reaction rim' is used.

Anorthositic Rocks.

Anorthosites form the second main group of rocks in the gabbro. They are prominent in the field, being readily recognized by their light color on weathered surfaces. Feldspars ranging in color from light grey-green and light pink to buff and brownish are the chief constituent. The brownish feldspars are most common in the more acid varieties. The anorthosites show medium to coarse grain and granitic texture. The feldspars, basic labradorite and acid bytownite, show much the same range in composition as those in the gabbros, but a gradation into acid plagioclase is also present. The feldspars are much altered, mainly to the clinozoisite varieties of the epidote series and to calcite. In some slides the alteration has directional features, being parallel to the cleavage planes of the feldspar.

The ferromagnesian components of the anorthosite are highly altered. In several slides the stumpy shape of the grains, and the birefringence of the less altered parts, suggest augite, which has in most cases altered to uralite (green hornblende), which has in its turn

altered to chlorite and epidote. The chief accessory minerals are magnetite, in rounded to shapeless grains altering to leucoxene, apatite in rod-like crystals, and in one slide biotite, which seemed to be a reaction product between magnetite and plagioclase. Secondary quartz and a brownish carbonate, probably ankerite, also occur. The gradation from gabbro to anorthosite is well shown by slides numbers F15:1 (30 percent ferromagnesian), F253X (25 percent), and F15 (15 percent).

At sta. A144 an outcrop which throws some light on the relative ages of anorthosite and gabbro was observed. The contact between anorthosite and gabbro seemed to be quite sharp with no chilling effects. However, for a few inches from the contact the anorthosite appeared to be abnormally low in ferromagnesians while the gabbro appeared to be rudely banded parallel to the contact. This suggests that the gabbro consolidated later than the anorthosite and that flow in the crystallizing gabbro or crystal mush along the sides of a block of anorthosite produced the banding. No veinlets of one rock in the other were found.

Another type of gradation is found in the eastern portion of the gabbro body, where a more acidic type of anorthosite has considerable areal extent. In nearly all places, however, little work was done on this type

since these rocks were so friable that it was seldom possible to trim a coherent hand specimen of them. The exposed surfaces of these rocks were pink to light brown and crumbly weathering, frequently overlain with a mantle of loose feldspar crystals (see pl.13A). The rock varied from 75 to 85 percent feldspar crystals about 1 cm. in diameter, and from 15 to 25 percent ferromagnesians which were in one place 15 percent hornblende and 10 percent biotite. The normal anorthosite seems to grade into this type without any abrupt change, as is indicated in the following sequence observed in the southeastern part of the body.

Location	Rock	
Sta. A145 to Sta. A147	Anorthosite and anorthositic gabbro	Banded in one place.
200 feet	Banded anorthosite	Trend 340°.
1650 feet	Banded anorthosite	Trend 315°.
2600 feet	Gabbroic anorthosite	
4300 feet	Gabbroic anorthosite	Trend of banding 318°.
Sta. A148	Coarse grained anorthosite	
3800 feet NW	Banded anorthosite	Trend 345°.

The material from sta. A148, believed to be representative of the more acid anorthosite, is made up of greenish feldspar crystals up to 1 1/2 cm. in diameter which on the weathered surface appear to be surrounded zonally and interstitially by pinkish feldspar, probably the result of weathering inwards from crystal

boundaries. It was determined by immersion methods to have the composition of basic oligoclase, $Ab_{77}An_{23}$. It also contains 10 percent of chloritized hornblende and a little magnetite.

These rocks are classed as anorthosites on a basis of field relationships and on their composition. Authorities do not specifically delimit anorthosite to plagioclase rock more basic than $Ab_{50}An_{50}$. Shand (1) states "the feldspar is usually bytownite or labradorite, but it may be andesine or even oligoclase. Mawdsley, in discussing the St. Urbain anorthosites (2), notes anorthosite composed of andesine, $Ab_{70}An_{30}$.

These acidic anorthosites are in general found in close proximity to the gabbro and granite contact, and are possibly a hybrid rock having been acidified by the granite. They are in many places cut by numerous aplitic dikes.

Another monomineralic differentiate noted was a band of massive titaniferous magnetite (at sta. F253). There an outcrop of dark, coarsely crystalline banded gabbro grades by increase in magnetite percentage and decrease of the other constituents into a rock contain-

(1) Shand, S.J., The Study of Rocks, T.Murby, 1932, p.98
(2) Mawdsley, J.B., St. Urbain Area, Charlevoix, Quebec, Geol. Surv., Canada, 1927, Mem. 152.

ing 85 to 100 percent magnetite with a little chalky white feldspar. The magnetite crystallized as octahedra when isolated. It contains an intergrowth of ilmenite, determined from calculations of a chemical analysis to be 20.9 percent. Immediately above the magnetite the rock is white weathering and quartz-bearing and is of the nature of a hybrid granite, believed to be intrusive. In any case, the relationship of gabbro grading into magnetite is definite.

Acid Rocks.

The acid rocks are less amenable to classification than the other groups since doubt exists as to their origin. Many of these may be aplitic dikes from the granite, others may be the "red rock" so common in differentiated basic intrusions. In this body it may be, at least in part, dikes cutting the more basic phases.

Mention has already been made of the types of granite found in the area. The main country rock is a coarse grained pink granite which in hand specimen showed about 40 percent of glassy quartz in irregular grains up to 1 cm. in diameter, 40 percent of fresh pink feldspar in large crystals up to 1 cm. in diameter, and about 20 percent highly altered ferromagnesian,

probably chloritic hornblende. In a thin section of one specimen the quartz was clouded with numerous gas and liquid inclusions. The feldspar seemed to be of two generations, an older altered oligoclase, and fresher feldspars, oligoclase and microcline. Hornblende and biotite, both bleached, were present and the accessories were apatite and magnetite.

Another type noted was the grey granite which composed the hill northeast of White Man lake. This rock showed coarse medium grain with about 40 percent of quartz in aggregates up to 1 cm. in diameter, 50 percent plagioclase, most of which was oligoclase, $Ab_{83}An_{17}$, with some microcline, altering to flakes and shreds of sericite, and about 10 percent of biotite. Apatite and zircon were accessory minerals. The rock may be classed as a tonalite.

The basic rocks of the gabbro body are cut by many medium grained, pink weathering dikes of aplitic aspect. These seem quite similar in the hand specimen, all being made up of pink feldspar, in places somewhat porphyritic, and a fine grained mass of pink feldspar, glassy quartz, and chloritic aggregates suggesting hornblende and biotite. In thin section a difference is noted. These rocks, which appear so fresh, are highly altered. They all have granitic texture. All show

fairly large, much altered crystals of a feldspar which falls within the range of acid andesine, and contains a heavy cloud of iron oxides. The ferromagnesians, while much bleached and altered to chlorite and epidote appear to have been hornblende and biotite. Zircon, magnetite, and apatite are the accessory minerals. Stringers of quartz and fresher feldspars, both microcline and oligoclase occur. The quartz in many places, especially in the absence of the fresher feldspar, appears contemporaneous with the altered feldspar. The numerous grains of quartz scattered through the altered feldspar frequently show simultaneous extinction suggesting granophyric texture. In a slide showing a dike-anorthosite contact a xenolith of anorthosite is surrounded by granophyre, (see pl. 8A). The slides studied suggest that there has been an intrusion of the dike rock, somewhat contaminated by xenoliths of country rock, followed by a slightly intrusion of the same dike rock along the same channels.

A somewhat different type was noted in two places. One (slide A136:1) is from a dike, the other (slide A138:5) from a small triangular intrusion into banded gabbro. In these the feldspar is made up of fresh and stained spindles which suggest microperthite. The

other constituents are quartz and hornblende, with magnetite, apatite, and zircon as accessory minerals. The quartz contains inclusions with gas bubbles showing Brownian movement.

The fact that the dikes are more numerous near the contacts, and that they contain zircon, an accessory mineral which has not been observed in the gabbro, suggests that these are aplitic dikes from the granite. Furthermore in several places pegmatite dikes, definitely connected with the granite cut the mass, and at one place the granite gabbro contact was observed, the granite sending off small aplitic dikes into the gabbro. The granophyric texture previously described ~~which~~ in some slides seems identical with photomicrographs of the Bushveld granophyre, some of which cuts the norite. At present, however, the mass of evidence appears to favor the conclusion that they are simply aplitic dikes.

Two slides of hybrid granites have been examined. They show fine grained, granitic, equigranular texture with occasional somewhat porphyritic crystals of grey feldspar in a groundmass of quartz, grey feldspar, (oligoclase, $Ab_{80}An_{20}$), and brown biotite bleached and altered to chlorite. Apatite, zircon, rutile?, and pyrite? were noted as accessories, the last named

mineral fulfilling the criteria of deuteric minerals given by Gillson (1).

(1) Gillson, J.L., Granodiorites of the Pend Oreille District of Northern Idaho, Jour. Geology, vol. 35, 1927, pp. 1-31.

PETROGRAPHY OF THE MAIN ROCK TYPES

In this chapter the thin sections studied are described in detail. They have been grouped for purposes of discussion into the main rock types, thus:

Gabbro slides.

A136 Olivine gabbro
A136:1 Contact of granitic dike and gabbro.
A137 Olivine gabbro
A138A Megalophitic gabbro
A138F Gabbro
A138:3 Hornblende gabbro
A140 Olivine gabbro
A144 Olivine gabbro
F15:1 Hornblende gabbro
F253X Anorthositic gabbro

Anorthosite slides.

A144:5 Anorthosite
A144:7 Contact of aplitic dike and anorthosite
A145X Anorthosite
A146X Anorthosite
A147 Anorthosite
F15 Anorthosite

Acid rock slides.

A136:1 Contact of granitic dike and gabbro
A138 Granite
A138:5 Tonalite
A144X Granitic dike?
A144:2 Granophyric aplite
A144:7 Contact of aplitic dike and anorthosite
A146 Aplite
F15:2 Granite
F249X Tonalite
F253:1 Contaminated granite
F253A Contaminated granite

Others.

A138:4 Spessartite
A144:3 Muscovadite

The locations from which these specimens were obtained are shown on map 1.

Gabbroic Rocks.

Specimen number	A136
Name	Olivine gabbro
Occurrence	Massive gabbro on west shore of Caribou Lake.

Macroscopic.

The hand specimen is a dark greenish grey rock with fine medium grain, made up of crystals of augite up to 2mm., lath-shaped individuals of dirty green feldspar averaging 2 by 1/2 mm., biotite and magnetite. A few specks of a yellowish sulphide whose lustre suggests pyrite are visible.

Microscopic.

The minerals observed in this rock are plagioclase feldspar, augite, olivine, biotite, magnetite, pyrite?, apatite, chlorite, calcite, serpentine(antigorite), leucoxene, and iron stain. The texture is poorly ophitic.

The feldspar crystals, which make up at least 50 percent of the rock, occur both in thin laths up to 3 by 1/2 mm. and as stubby crystals averaging 2 by 1 mm. X' on 010 in 001 cleavage fragments is 25^{o}, making the plagioclase bytownite ($Ab_{19}An_{81}$). It is euhedral to all the other minerals in the rock, but contains small crystals of apatite. The feldspar is quite dusty contain-

ing submicroscopic needles of dark mineral. It alters to calcite, and some secondary chlorite occurs within the feldspar.

The augite crystals are thickly shot with orientated inclusions of a dark mineral (see pl. 4A). These have two directions, one of which is parallel to the front pinacoid. Where the augite is twinned the inclusions give a herringbone structure. Apart from the darkening due to the inclusions, the augite is colorless and non-pleochroic. It alters in a few places to biotite and chlorite.

The olivine present is interstitial to the feldspar, and in one place the augite seems moulded on it. It is optically negative, hence contains more than 13 percent FeO. It contains iron oxides as alteration products and also alters to the non-fibrous variety of serpentine, antigorite.

The opaque minerals present, magnetite and pyrite?, occur in rather shapeless grains. The magnetite seems to be moulded on the augite. There are numerous reaction rims of biotite between the plagioclase and mafic minerals. Some of the magnetite has altered to a rather bright, opaque yellow mineral probably leucoxene.

Specimen number	A136:1
Name	Contact of granitic dike and gabbro.
Occurrence.	Dike cutting gabbro on the west shore of Caribou Lake.

Megascopic.

Light colored dikes up to 4 inches across cut the gabbro. One of these shows a coarse grained border against the country rock with feldspar crystals up to 1 inch long. The middle of the dike is composed of buff to dirty green feldspar 60 percent, quartz 30 percent, chloritized hornblende and chlorite 10 percent.

Microscopic.

This slide shows parts of the gabbro country rock described as slide A136 (q.v.) and part of the granitic dike. The minerals of the gabbro are essentially the same as previously described but more highly altered. The feldspar is altered to a dense aggregate of flakes and shreds of clinozoisite?. The augite where unaltered still contains needles. An alteration sequence is particularly well illustrated, the augite altering to a green-blue pleochroic hornblende (uralite)(see pl. 5A), which in turn is followed by a green mica, then straw colored, highly pleochroic biotite. The latter alters to a feebly pleochroic green chlorite, penninite. The rock contains titanite in one or two places whose close association

with the ferromagnesian minerals and oxides suggests a secondary origin.

The dike is made up of quartz, feldspar, and hornblende. Its texture is pegmatitic and it has a chill phase 3/4 to 1 mm. wide with banding of hornblende parallel to the contact. The quartz contains several inclusions of liquid with bubbles which when 0.002 mm. or less in diameter show Brownian movement. Two types of feldspar are evident, one suggesting perthitic texture by differential clouding with iron oxide. It is in any case one of the acidic feldspars, having negative sign and low index. The second kind of feldspar occurs in small grains on the contact, and as stringers extending into the gabbro. It is optically positive and as determined by the statistical method is $Ab_{90}An_{10}$.

Specimen number	A137
Name	Olivine gabbro
Occurrence	Massive gabbro on the west shore of Caribou Lake.

Megascopic.

The fresh surface of the rock is medium grained and dark greenish grey, with olive green feldspar in lath-shaped crystals, black augite with good cleavage faces, some magnetite and a little biotite. One aggregate

2 mm. long of yellowish metallic mineral was evident.

Microscopic.

The constituents of the rock are basic bytownite ($Ab_{15}An_{85}$) 69.8%, augite 19.6%, magnetite and pyrite 5.3%, olivine 4.2%, biotite 1.1%, apatite, hornblende, chlorite, calcite, clinozoisite, serpentine (antigorite), and iron stain. The percentages were determined by Rosiwal analyses of two slides. The biotite content as reported is low, since it occurs as very narrow reaction rims around the ferromagnesians and opaque minerals. The texture is megalophitic (see pl. 5B).

The most abundant constituent is a basic bytownite in lath-shaped crystals averaging 3 by 1/2 mm. and stouter oblong crystals averaging 3 by 2 mm. It shows albite, Carlsbad, and pericline twinning. By its extinction angle of 29° for X on 010 in basal cleavage plates it is $Ab_{15}An_{85}$.

The augite is, where not filled with orientated needles of ilmenite?, faintly pleochroic from colorless to pale yellow brown. Although fairly fresh in this slide it shows the reaction series, augite→uralite (green hornblende), the latter altering to chlorite.

The olivine is an iron rich variety, being optically negative. It shows one fairly distinct cleavage. It alters to serpentine (antigorite).

The opaque minerals show reaction rims of brownish mica with the plagioclase. A yellow sulphide, probably chalcopyrite, is present in fair amounts. Its shape is that of Gillson's deuteric.

The sequence of crystallization as shown in this slide is feldspar, olivine, then probably augite and magnetite together, the latter crystallizing when the former had ceased. Some of the feldspar crystals show evidence of crushing during crystallization.

Specimen number	A138A
Name	Megalophitic gabbro.
Occurrence	One of the lighter weathering bands in an exposure showing stratiform differentiation on the west shore of Caribou Lake.

Megascopic.

The fresh surface of this rock shows a rather confused aggregate of murky grey feldspar, principally in laths, suggesting ophitic texture, but with some chunky feldspars, and about even proportions of chunky and lath-shaped crystals from 3 to 7 mm. in diameter.

Microscopic.

The rock contains plagioclase feldspar, pyroxene, probably augite, secondary hornblende, biotite, chalcopyrite, magnetite, apatite, clinozoisite, chlorite.

The texture is megalophitic.

The feldspar occurs in lath-shaped crystals. It appears to be of two kinds, one, having Z on 001 in cleavage fragments parallel to 010 about 28°, is $Ab_{32}An_{68}$. The other is about $Ab_{12}An_{88}$, with Z on 010 in basal cleavage fragments $26\ 1/2^{\circ}$.

The pyroxene, where unaltered, contains the oriented inclusions giving schiller structure. It is highly altered to a pleochroic blue green hornblende, which is twinned in places. They both alter to chlorite as does the biotite present.

In addition to the magnetite there is a yellowish metallic mineral determined in the hand specimen as chalcopyrite.

The sequence of crystallization is here feldspar, then magnetite and pyroxene, the latter apparently having ceased crystallizing first.

Specimen number	A138F
Name	Gabbro
Occurrence	One of the darker weathering bands in an outcrop showing stratiform differentiation, on the west shore of Caribou lake.

Megascopic.

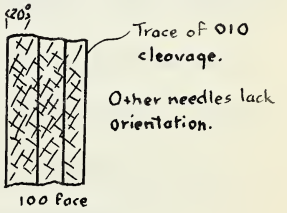
The constituents of the rock are plagioclase

feldspar, in laths which penetrate and are enclosed by plates of a stumpy dark mineral determined microscopically as augite, magnetite, biotite, and a yellow metallic mineral, probably pyrite. The rock is coarse medium grained.

Microscopic.

Under the microscope the rock is seen to consist of plagioclase feldspar ($Ab_{37}An_{63}$), augite, hornblende, magnetite, apatite, chlorite, clinozoisite?, iron stain. The texture is megalophitic, in part sideronitic (see pl. 4B).

The plagioclase is in euhedral crystals, most of which are lath-shaped averaging 3 by 1/2 mm., but some are stubby, 2 by 1 mm. They show Carlsbad, albite, and pericline twinning. The feldspar contains orientated needles of what in the augite was considered ilmenite. They are approximately orientated as shown. The feldspar contains a little clinozoisite, but is fresh in appearance.



Augite occurs in rather large grains up to 4 mm. in maximum diameter. Some of the larger grains present a poikilitic appearance. It contains many orientated inclusions of ilmenite?, but where clear is

non-pleochroic, and light yellow brown. It alters to uralite (green hornblende) and chlorite, but most of all to biotite, the crystals when in contact with the plagioclase showing small flakes of biotite projecting into the plagioclase. These seem to parallel the albite twinning.

"Magnetite" grains consisting of two minerals, probably magnetite and ilmenite, were noted. They are penetrated by the feldspar but seem to assert their crystal outlines against the augite. The grains are surrounded by rims of biotite, in part like the spine-like flakes noted above. This is in turn succeeded by a zone showing vermicular intergrowths of plagioclase feldspar, a greenish mineral, probably chloritized hornblende , and sometimes biotite. The base of some of these intergrowths is against the biotite with the curved ends against the feldspar, in others the reverse relationship occurs. This structure has been termed "symplectite" (1), by Sederholm, who attributed it to metamorphism from a granitic intrusion. Hills (2), however, attributes it to paulopost reaction.

(1) Sederholm, J.J., Op. cit., p. 46.
(2) Hills, E.S., An unusual occurrence of myrmekite, and its significance, Geol. Mag., vol. 70, 1933, p. 294-301.

The slide shows this type of reaction rim particularly well (see pl. 6A). One or two intergrowths of magnetite suggest the former presence of olivine. Apatite occurs in rod-like crystals in the feldspar and in one case cuts the biotite.

Specimen number	A138:3
Name	Hornblende gabbro
Occurrence	As a band of stratiform differentiate, on the west side of Caribou Lake.

Megascopic.

The rock shows medium to coarse grain with fibrous green mineral, determined microscopically as hornblende, surrounded by dull white to light buff, pink, etc., material, probably altered feldspar. In places in the rock carbonate occurs. Tiny brownish aggregates of biotite are present in small amounts. Specks of metallic minerals are also present.

Microscopic.

The constituents of the rock are hornblende, plagioclase, titanite, magnetite, pyrite, clinozoisite, chlorite, and calcite. The texture is granitic.

The most abundant mineral of the rock is common hornblende. It is highly pleochroic with X = light yellow,

Y = dark brown, Z = brownish green. The maximum value of Z on c noted was 22°. Twinned crystals were noted.

The feldspar is almost completely altered. Its index shows it to be more basic than $Ab_{88}An_{12}$. In some places it is entirely replaced with columnar to radiating aggregates of clinozoisite. This mineral is optically positive, and its birefringence places it at about 8 to 9 molecular percentage of the $HCa_2Fe_3Si_3O_{13}$ molecule, (1). It is therefore almost common epidote. Clinozoisite also occurs as shreds within badly altered feldspar. This slide is illuminating since in the others the material is seen only in small shreds. Stringers of this mineral also cut the hornblende crystals.

Magnetite and pyrite? are accessories, in association with which are several subhedral crystals of pleochroic titanite up to 0.3 mm. in diameter.

Specimen number	A140
Name	Olivine gabbro.
Occurrence	Massive outcrop of gabbro at the west end of White Man lake.

Megascopic.

The rock is a medium grained gabbro, rather low

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(1) Winchell, A.N., Elements of Optical Mineralogy, Part II, 3rd Ed., 1933, p. 313.

in feldspar. It contains a little biotite.

Microscopic.

The minerals observed are plagioclase feldspar, augite, olivine, biotite, magnetite, pyrite, apatite, iron stain, calcite, serpentine (antigorite), penninite?, leucoxene. It has subophitic texture.

The plagioclase is a comparatively fresh labradorite ($Ab_{43}An_{57}$), in lath-shaped and stubby crystals, which show albite and a considerable amount of Carlsbad twinning.

The augite is almost as abundant as the plagioclase. It contains orientated inclusions of ilmenite? giving schiller structure. Numerous "blebs" of magnetite also occur in it.

Olivine, in rounded grains, is the most altered mineral in the slide. The fresher grains are surrounded by a narrow border of augite. Some have altered to a mass of antigorite and iron oxides. Others seem surrounded by a zone of magnetite followed by a zone of leucoxene and calcite.

Around the grains of olivine and opaque mineral is a zone of penninite?-plagioclase symplectite, which is separated from the opaque minerals by a zone of biotite. A yellow sulphide constitutes a considerable amount of the accessory opaque minerals.

Specimen number	A144
Name	Olivine gabbro
Occurrence	Massive outcrop on ridge southeast of Caribou lake.

Megascopic.

The hand specimen shows a fine medium grained rock consisting of dull, pale green feldspar, approximately 25 percent, and black shiny material, determined microscopically as titaniferous augite, slightly brownish in places when mixed with biotite. The cleavage faces of the feldspars appear to show a lath-like arrangement. At places on the joint cracks of the rock a dull greenish bloom is present.

Microscopic.

The rock is made up of titaniferous augite, plagioclase feldspar, olivine, biotite, magnetite, serpentine (antigorite), clinozoisite and iron stain. Its texture is granitic.

Titaniferous augite is the most abundant constituent of the rock, at least 50 percent of this mineral being present. It is optically positive, and exhibits weak reddish violet pleochroism, as X = light yellow, Y = reddish purple, Z = light grey. It alters to a brown hornblende, whose pleochroism is X = clear yellow, Y = golden brown, Z = reddish brown, to brown biotite, and is stained yellow with iron oxide.

The olivine is in rounded grains, altering to serpentine (antigorite), and iron oxides. At least 20 percent of this mineral is present.

The plagioclase, making up about 25 percent of the rock, is at least as basic as labradorite, $Ab_{45}An_{55}$, by three measurements on the statistical method. It is much altered, to one of the epidote minerals, probably within the clinozoisite range.

The biotite present is nearly all secondary.

Specimen number	F15:1
Name	Hornblende gabbro
Occurrence	An outcrop of massive gabbro northeast of the east end of Trout lake.

Megascopic.

The rock shows considerable local variation in appearance, the bulk of it showing on the fresh surface black hornblende, 40 percent, pale green feldspar 50 percent, and biotite 10 percent. Some magnetite is evident. It is medium grained and in places shows megalophitic texture.

Microscopic.

Microscopic examination revealed as constituents of the rock, plagioclase feldspar, hornblende, biotite, magnetite, titanite, calcite, dipyre, chlorite, clino-

zoisite, leucoxene. The rock shows granitic texture.

Plagioclase feldspar, basic labradorite (Ab_{30} An_{70}), is the most abundant constituent. It is highly altered to clinozoisite?, and in some places to dipyre and calcite. The dipyre shows distinctly the characteristic prismatic and pinacoidal cleavages.

The predominant ferromagnesian is a highly pleochroic hornblende, which in one place showed zoning, yellowish brown→greenish brown→blue green, (see pl. 7A). Alteration of the hornblende has proceeded far. It has gone over to biotite, to chlorite, and to calcite. Although much of the biotite is secondary, some is primary. This latter contains tablets of plagioclase along the cleavage planes.

Some of the magnetite has gone to leucoxene. In one place, an aggregate of magnetite, which seems to be arranged in a rectangular net-like pattern, is associated with titanite, calcite, biotite, and a grain of plagioclase (see pl. 6B).

A grain of apatite cuts across several feldspar grains and a hornblende grain.

Specimen number	F253X
Name	Anorthositic gabbro
Occurrence	Body of massive, white weathering rock at the northwest end of Mad lake.

Megascopic.

On the weathered surface the rock is dull white and appears to be mostly feldspar. The hand specimen shows a coarsely crystalline anorthositic gabbro with olive green to pink feldspar in crystals up to 1 1/2 cm., forming about 75 percent of the rock, and a dark mineral with good cleavage, determined microscopically as augite in part altered to hornblende, occurring as clumps of crystals to make 25 percent of the rock.

Microscopic.

The rock is made up of plagioclase feldspar, augite, hornblende, biotite, apatite, chlorite, clinozoisite, and calcite. It has been so highly altered that the texture is obscured, but it appears to be megalophitic.

The plagioclase feldspar, which is found in large crystals averaging 3 by 2 mm., is almost too altered to determine. One crystal perpendicular to Y gave its composition as $Ab_{35}An_{65}$. It is now a mass of clinozoisite and calcite. Chlorite with very good ultra blue birefringence also occurs in the feldspar.

The ferromagnesian is augite, non-pleochroic and conaining orientated inclusions (schiller structure). It shows rims of biotite and in places hornblende. A little of the hornblende may be primary, but most of the hornblende and biotite is secondary.

A large individual of apatite in a plate of hornblende was noted.

Anorthositic Rocks.

Specimen number	A144:5
Name	Anorthosite
Occurrence,	Massive outcrop, southeast of Caribou lake.

Megascopic.

The anorthosite is grey weathering, speckled with green and dark spots of ferromagnesian. The fresh surface shows coarse medium grained rock consisting largely of light olive green to buff feldspar, a small amount of biotite, and aggregates of altered ferromagnesian. A small amount of secondary quartz was evident.

Microscopic.

The rock is made up of plagioclase feldspar, amphibole, iron oxide, apatite, chlorite, calcite, clinozoisite. The texture is granitic but the arrangement of the hornblende suggests directional features.

EXPLANATION OF PLATE 4.

A. Photomicrograph of augite in gabbro, (spec. A137), showing oriented inclusions of ilmenite? The heavy lines are the prismatic cleavage of the augite.
X 250. Ordinary light.

B. Photomicrograph of gabbro, (spec. A138E), showing a large individual of magnetite penetrated by feldspar laths, giving the rock a sideronitic texture.
X 25. Ordinary light.

EXPLANATION OF PLATE 4.

A. Photomicrograph of augite in gabbro, (spec. A137), showing orientated inclusions of ilmenite?. The heavy lines are the prismatic cleavage of the augite.
X 250. Ordinary light.

B. Photomicrograph of gabbro, (spec. A138F), showing a large individual of magnetite penetrated by feldspar laths, giving the rock a sideronitic texture.
X 25. Ordinary light.

PLATE 4

A

B

PLATE 5

EXPLANATION OF PLATE 5

A. Photomicrograph of altered gabbro, (spec. A130:1), showing ribs of uralite (ur) about augite (aug). Highly altered bytownite (f) is also present.
X 45. Ordinary light.

B. Photomicrograph of coarsely ophitic gabbro, (spec. A132). Plagioclase crystals penetrate augite, which shows sonillar structure.
X 33. Ordinary light.

EXPLANATION OF PLATE 5

A. Photomicrograph of altered gabbro, (spec. A136:1), showing rims of uralite (ur) about augite (aug). Highly altered bytownite (f) is also present.
X 36. Ordinary light.

B. Photomicrograph of coarsely ophitic gabbro, (spec. A137). Plagioclase crystals penetrate augite, which shows schiller structure.
X 33. Ordinary light.

PLATE 5

A

B

PLATE 6

EXPLANATION OF PLATE 6.

A. Photomicrograph of [illegible] (Spec. A1388), showing resorption rims. The [illegible] is surrounded by a rim of biotite, which is enclosed in a rim of chloritized hornblende and plagioclase feldspar in vermicular intergrowths. This structure is termed a symplectite by Sederholm.
X 68. Ordinary light.

B. Photomicrograph of gabbro (specimen T13:1), showing magnetite in a tectangular pattern associated with titanite in wedge shaped grains, and with calcite. The whole is enclosed in altered plagioclase.
X 36. Ordinary light.

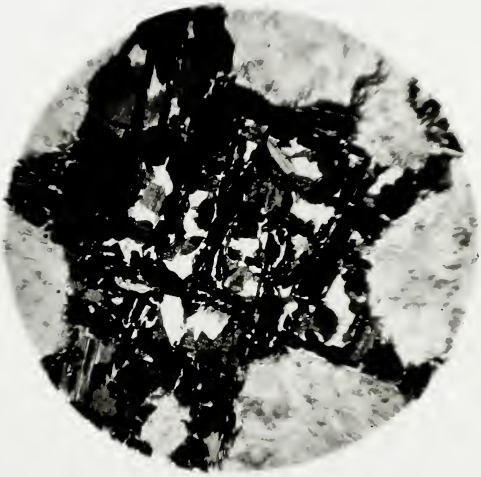
EXPLANATION OF PLATE 6.

A. Photomicrograph of gabbro, (spec. A138F), showing reaction rims. The magnetite is surrounded by a rim of biotite, which is enclosed in a rim of chloritized hornblende and plagioclase feldspar in vermicular intergrowths. This structure is termed a symplectite by Sederholm.
X 68. Ordinary light.

B. Photomicrograph of gabbro (specimen F15:1), showing magnetite in a rectangular pattern associated with titanite in wedge shaped grains, and with calcite. The whole is enclosed in altered plagioclase.
X 36. Ordinary light.

PLATE 6

A



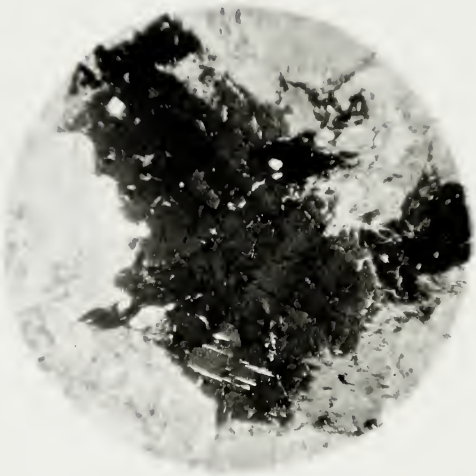
B

EXPLANATION OF PLATE 7.

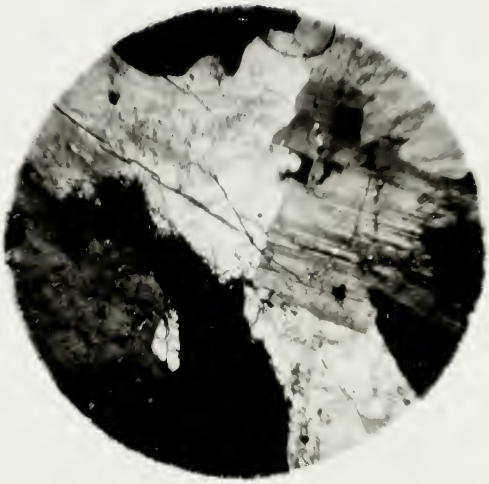
A. Photomicrograph of hornblende in gabbro (spec. F15:1). The hornblende shows zoning, the interior zone being yellowish brown, the middle brownish green, and the margin blue green.
X 25. Ordinary light.

B. Photomicrograph of anorthosite (spec. A145X), showing labradorite and much altered interstitial ferromagnesian.
X 25. Crossed nicols.

PLATE 7



A



B

The feldspar, a basic labradorite of composition $Ab_{30}An_{70}$, occurs in subhedral, equidimensional grains averaging about 2 by 2 mm. It is much altered to calcite and an epidote mineral, probably clinozoisite. The alteration is directional, seemingly paralleling the cleavage of the feldspars.

The ferromagnesian mineral is now a mass of calcite and chlorite. The presence of the former, and the fibrous appearance of the grains, suggest a calcium amphibole, possibly actinolite.

A few grains of iron oxide, for the most part in the ferromagnesian, have a dull yellow lustre.

Specimen number	A144:7
Name	Contact of anorthosite and aplitic dike.
Occurrence	Aplitic dike cutting anorthosite, south of Caribou lake.

Megascopic.

The hand specimen shows the contact of pink, rather fine medium grained aplite with the medium grained green anorthosite, the aplite sending off stringers into the anorthosite.

Microscopic.

This slide shows the contact of the anorthosite described as slide A144:5 and an aplitic dike described

as A144:2. The anorthosite is a more highly altered variety of the type described as A144:5. It contains the same minerals, and in addition one or two grains of zircon have been introduced close to the dike contact.

The dike rock is the same in mineral content, mainly altered plagioclase, quartz, hornblende and mica. It has developed marked granophyric texture, (see pl. 8A), about the contact. This in one place surrounds a xenolith of feldspar from the anorthosite.

Specimen number	A145x
Name	Anorthosite
Occurrence	Massive outcrop of coarse grained anorthosite, southeast of Caribou lake.

Megascopic.

The rock is coarse medium grained. It is almost entirely light green and pink to buff feldspar, in places showing both Carlsbad and albite twinning, and in one place slightly zoned. A little biotite, magnetite, and chlorite are also present.

Microscopic.

Under the microscope the rock is seen to consist of plagioclase feldspar, a badly altered ferromagnesian, apatite, calcite, epidote, chlorite, iron stain, and

some introduced quartz, orthoclase and calcite. The texture is granitic.

The plagioclase occurs in equidimensional octahedra about 2 by 2 mm., (see pl. 7B). Its composition, although difficult to determine exactly, is within the labradorite range. It alters to calcite and to an epidote mineral, probably clinozoisite.

The ferromagnesian mineral, which is interstitial to the feldspar, is too altered to determine, a mass of chlorite, calcite, and epidote. The slide contains considerable accessory apatite.

In addition to the above, there is some secondary quartz and calcite, two veinlets of the latter appearing to be ankerite, and some introduced alkali feldspar, which was determined as orthoclase.

Specimen number	A146 X
Name	Anorthosite
Occurrence	Massive outcrop southeast of Caribou lake.

Megascopic.

The fresh surface of the rock shows tabular feldspars over 2 cm. long, showing albite twinning. Their color ranges from greenish grey through pale buff to pale pink. The rock contains considerable amounts of a pinkish grey mineral, having the same

same color and lustre when wet as native silver.

Microscopic.

Microscopic examination shows the rock to consist of plagioclase feldspar, pyroxene?, apatite, magnetite, epidote?, calcite, chlorite, leucoxene, and quartz. The texture is granitic.

The chief constituent of the rock is an acid bytownite, $Ab_{22}An_{78}$. It occurs in equidimensional, subhedral,grains, averaging 2 by 2 mm. It alters to calcite and to an epidote mineral, probably clinozoisite.

The ferromagnesian, whose shape suggests a pyroxene, is now too altered to determine. It is a mass of epidote, calcite and chlorite, the last named mineral occurring in radiating aggregates.

A large individual of apatite, some leucoxene, and some introduced quartz are the other minerals in the rock.

Specimen number	A147
Name	Anorthosite
Occurrence.	Outcrops of grey to pinkish brown, rather altered anorthosite, south of Caribou lake.

Megascopic.

The fresh surface shows coarse grained olive-

green feldspar and very little else. A small amount of secondary quartz and calcite are present.

Microscopic.

The rock contains plagioclase feldspar, pyroxene, apatite, magnetite, hornblende, chlorite, calcite, clinozoisite, leucoxene, quartz. The texture is granitic.

The plagioclase feldspar is acid bytownite, $Ab_{26}An_{74}$. It forms rather large, equidimensional crystals up to 4 mm. across. Calcite and clinozoisite are the main alteration products.

The ferromagnesian is now a mixture of hornblende and chlorite. It may have been augite, although the structure is suggestive of olivine. Some magnetite is present as irregular grains, now largely leucoxene. A considerable amount of apatite in euhedral crystals up to 1 by 1/2 mm. is the other accessory mineral. Some large grains of secondary calcite and quartz occur.

Specimen number	F15
Name	Anorthosite
Occurrence	Massive outcrop, 1/2 mile south of nickel showing.

Megascopic.

The rock is a pale green coarse grained anorthosite.

Microscopic.

The rock consists of plagioclase feldspar, augite?, biotite, magnetite, apatite, chlorite, zoisite, -calcite, leucoxene, The texture is granitic.

The plagioclase is highly altered. Two measurements by the statistical method show it is at least as basic as $Ab_{50}An_{50}$. It is now a mass of zoisite, calcite, and chlorite.

The ferromagnesian, also badly altered, suggests augite by its shape, color and birefringence. It alters to chlorite and epidote. A little biotite, apatite, and magnetite are present. The last named mineral alters to leucoxene and also has in places a rim of biotite. In one place a network of magnetite laths surrounded by leucoxene occurs in a large biotite individual. The network suggests a rhombohedral arrangement.

Granitic Rocks.

Specimen number	A138:5
Name	Tonalite
Occurrence	Massive granite near gabbro contact, on northwest shore of Caribou lake.

Megascopic.

The rock is coarse medium grained, pink weathering, and is made up of pink to white feldspar, an equal proportion of rusty looking quartz and about 20 percent

ferromagnesian. The white feldspar is cut by stringers of the red, and some crystals show albite twinning.

Microscopic:

The minerals of the rock are quartz, microcline, plagioclase feldspar, hornblende?, biotite, apatite, magnetite, sericite, chlorite, iron oxide. The texture is granitic.

The quartz is dusty looking, with lines and clusters of cavities which contain bubbles, and with needle-like crystals of apatite.

The rock appears to contain two generations of feldspar. One is in large rather altered crystals and by immersion methods was determined to be oligoclase, although the albite twinning is neither prominent nor abundant. It is largely altered to sericite. There are also a number of smaller crystals of microcline and oligoclase in about equal proportions. These are less altered and seem to have brought about a regrowth in the old feldspars. The second generation is probably due to a later stage of magmatic action.

The ferromagnesians are almost completely altered to a dirty green chlorite. The remnants suggest both bleached and chloritized hornblende and biotite. Some yellow oxide of iron is present, an alteration product of the magnetite.

Specimen number	A138:6 and A138
Name	Tonalite?
Occurrence	Patch of "granite" 4 ft. by 4ft. by 5 ft. intruding gabbro, on the northwest shore of Caribou lake.

Megascopic.

The 'granite' is uniformly pink weathering, and varies from a medium fine grained aplitic phase to a coarse grained pegmatitic phase, the latter having crystals up to 1 inch across. The most common phase is a medium coarse grained rock consisting of salmon pink feldspar (45 percent), milky quartz (40 percent), and magnetite (15 percent).

Microscopic.

Slide A138 is typical of the medium grained phase while A138:6 is a magnetite rich segregation. The constituent minerals of the rock are quartz, perthite, magnetite, apatite, zircon, hematite. The texture is coarse grained granitic.

The quartz present is in rather large crystals which seem dusty because of inclusions of liquid containing bubbles. It is also present as smaller crystals in the feldspar which give the effect of granophyre by simultaneous extinction.

The differential iron staining of the feldspar spindles strongly suggests perthite. Its index is

less than Canada balsam.

Much euhedral magnetite with rectangular outlines, in places altering to red oxide of iron, is present. Some crystals of zircon occur, one of which is seen under the high power to be associated with small amounts of an undetermined purple mineral.

From its marked similarity to the dike rock of slide A136:1, and from the presence of zircon, not found in the gabbro, it is inferred that this rock is genetically connected with the granite (tonalite).

Specimen number	A144X
Name	Granitic dike?
Occurrence	Isolated outcrop in muskeg south of Caribou lake.

Megascopic.

The rock is pink weathering, and in as fresh a specimen as could be obtained, is made up of pink feldspar (80 percent), chlorite (10 percent) and quartz (10 percent). The texture is rather coarsely granitic, cut by quartz and plagioclase stringers.

Microscopic.

In thin section the rock is seen to consist of microcline, plagioclase feldspar of two generations, hornblende, quartz, zircon, apatite, titaniferous

magnetite?, epidote, calcite, hematite, leucoxene.

The rock contains two types of feldspar, showing Carlsbad and albite twinning, and in two or three places apparently microcline. The oldest, most altered feldspar is andesine, $Ab_{61}An_{39}$. It contains clouded iron oxides, and is cut by stringers of quartz and albite of the composition $Ab_{90}An_{10}$, and in places contains grains of albite and quartz in granophyric groups. The quartz contains inclusions with bubbles. Zircon and apatite are common accessories, and from the leucoxene the former presence of titaniferous magnetite is inferred. The slide contains much iron oxide.

The nature of the rock apparently indicates a granitic dike which either contains xenoliths of anorthosite or of an early phase of the granite.

Specimen number	Al44:2
Name	Granophyric aplite.
Occurrence	Aplitic dike cutting gabbro southeast of Caribou lake.

Megascopic.

The dikes are fine grained, and on the fresh surface appear to be made up of quartz and pink feldspar with a very little chlorite.

Microscopic.

The constituent minerals of this rock are

quartz, plagioclase feldspar, hornblende, mica, apatite, -magnetite, chlorite, red oxide of iron, leucoxene. The texture is poorly granophyric.

The quartz occurring as blebs and stringers in the altered feldspar, suggest granophyre by its simultaneous extinction. It contains gas and liquid inclusions. The plagioclase feldspar, which is at least as basic as acid andesine, is highly altered. It is full of infinitesimal specks of some dark mineral and also of red oxide of iron. The iron oxide seems to have come in along the joints of the rock.

Specimen number	A146
Name	Aplite
Occurrence	Thirty foot aplitic dike cutting anorthosite.

Megascopic.

In the centre of the dike the rock is medium grained, slightly porphyritic, with pink feldspars up to 1 cm. in a medium to fine grained ground-mass of glassy quartz, pink feldspar and chloritic aggregates.

Microscopic.

The minerals of the rock are plagioclase feldspar of two generations, quartz, hornblende?, magnetite, apatite, zircon, epidote?, chlorite. The

rock shows granitic texture.

Two ages of feldspar occur in the rock. The first is as least as basic as acid andesine according to two measurements by the statistical method. It is very heavily dusted with iron oxide. Some crystals seem to have been replaced by fresher feldspar, which also occurs as stringers with the quartz and as individual crystals. It is an acid oligoclase about $Ab_{90}An_{10}$ by a determination on a combined albite-Carlsbad twin. A little orthoclase may also be present. In one place the newer feldspar shows a myrmekitic texture, (see pl. 8B).

The ferromagnesian, whose shape and color suggest hornblende, is now altered to a mass of epidote and some calcite. A stringer of hornblende cuts across the slide. A little magnetite and zircon are also present.

The slide suggests that the rock was fractured subsequent to the intrusion of the rock which contains the old feldspar, and that quartz, fresh plagioclase, and hornblende were then introduced.

Specimen number	F15:2
Name	Granite
Occurrence.	Massive, aplitic rock which may cut the gabbro, 1/2 mile south of the nickel outcrop.

Megascopic.

On the fresh surface the rock is medium grained and pink, and is made up largely of quartz and pink feldspar with very little ferromagnesian.

Microscopic.

The rock consists of alkali feldspar, quartz, plagioclase, apatite, zircon, hematite, chlorite, calcite, epidote. The texture is granitic.

The feldspar is heavily dusted with red oxide of iron making determinations uncertain. Alkali feldspar is suggested in many grains by the negative sign and low refringence, while some which shows albite twinning is about albite in composition. The fresher feldspar is in small grains, of about the same refringence and birefringence as the other.

Quartz is abundant in rounded anhedra about 1/2 mm. in diameter. It contains many inclusions with bubbles. The former ferromagnesian is now almost wholly altered to epidote and chlorite. The slide also contains zircon and apatite, with secondary calcite.

The appearance of the slide, together with the proximity of the nickel veins suggest that this was

an aplitic dike from the granite which suffered considerable hydrothermal alteration by iron-rich solutions.

Specimen number	F249X
Name	Tonalite
Occurrence	Grey granite stock?, northeast of White Man Lake.

Megascopic:

On the fresh surface the rock is coarse medium grained, with 40 percent of quartz crystals up to 6 mm., 45 percent of white and pink feldspar crystals, and 15 percent of biotite.

Microscopic:

The rock consists of quartz, oligoclase, microcline, biotite, apatite, zircon, chlorite, calcite, sericite. The texture is granitic.

Quartz occurs in individuals up to 3 mm. It is comparatively fresh, traversed by a few dusty lines, the particles of which are cavities containing bubbles.

The plagioclase feldspar is mostly oligoclase, $Ab_{83}An_{17}$, X on 010 in basal cleavage plates being 10^{o}, and X on 001 in 010 cleavage plates being 2^{o}. Some microcline is also present. The feldspar alters to patches of flakes and shreds of sericite, these paralleling the cleavages, The microcline is much more altered

than the oligoclase. It contains a little calcite. A little biotite, altering to chlorite, is present but much less in the slide than in the hand specimen. Other accessory minerals are apatite and zircon.

Specimen number	F253:1
Name	Contaminated granite.
Occurrence	As massive outcrop of intrusive granite above magnetite band at sta. F253, north of Mad lake.

Megascopic.

The rock is fine grained and white weathering. and contains small inclusions of bedded sediments. The fresh surface shows somewhat porphyritic texture with grey feldspar phenocrysts up to 6 mm. in a groundmass of quartz, grey feldspar, and biotite.

Microscopic.

The constituents of the rock are quartz, plagioclase feldspar, mica, apatite, zircon, rutile?, sericite, chlorite, calcite. The texture is granitic, (see pl. 9A).

The most abundant mineral is quartz, in rounded to subangular grains, which contain bubble bearing inclusions. The feldspar is an oligoclase, $Ab_{80}An_{20}$. It shows in one or two places albite and perhaps pericline

twinning, but is for the most part untwinned. It is highly altered to sericite.

Much mica, both bleached and altered to chlorite, is present. Accessory minerals are apatite, in the quartz and plagioclase, zircon, in quartz, plagioclase, and biotite, where it forms pleochroic haloes, and euhedral crystals of a dark brown mineral, probably rutile?.

Specimen number	F253A
Name	Contaminated granite.
Occurrence	Outcrop of contaminated granite showing many inclusions, north of Mad lake.

Megascopic.

The rock is rusty white on the weathered surface, containing many small rusty weathering inclusions of bedded sediments. The fresh surface reveals a fine grained rock made up of grey feldspar, quartz, and biotite, with a little pyrite.

Microscopic.

Microscopic study shows the rock consists of quartz, plagioclase, biotite, zircon, calcite, pyrite, apatite, rutile, chlorite, sericite. The texture is granitic, equigranular.

This rock is very similar to that described as F2531. The quartz also contains the inclusions with bubbles. The feldspar appears to have about the same composition, an oligoclase. Considerable biotite is present, altering to radiating masses of chlorite.

Apatite, zircon and rutile are the accessory minerals. Some calcite, probably of hydrothermal origin. The rock contains pyrite in shapless blebs, which according to Gillson is evidence of deuteric origin, (1).

Specimen number	A138:4
Name	Spessartite.
Occurrence	Dark fine-grained dike cutting gabbro on the northwest shore of Caribou lake.

Megascopic.

The dike shows chilled margins against the gabbro. Its fresh surface is fine grained, and jet black, with a suggestion of ophitic texture.

Microscopic.

The rock contains hornblende, plagioclase feldspar, biotite, pyrite, magnetite, and iron stain. The

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(1) Gillson, J.L., Granodiorites of the Pend Oreille District of Northern Idaho, Jour. Geol., vol. 35, 1927, p.23.

texture is ophitic with glomeroporphyritic aggregates of hornblende.

The hornblende, in pleochroic anhedra, forms a little over half the rock. The maximum value of Z on c noted was 25°, the mineral was optically negative, and the composition was checked by the position of Z. The average size of grain is 1/2 mm.

The plagioclase has the composition of a basic andesine, $Ab_{57}An_{43}$, by three measurements using the statistical method. It occurs in lath-shaped crystals averaging 2 by 1/2 mm.

A little biotite and magnetite are present, and a considerable amount of pyrite in shapless octopus-like patches.

The rock is a lamprophyre (spessartite). According to Grout (1), the rock is probably from a diaschistic dike, coming from the granite, although it may be diabase.

Specimen number	A144:3
Name	Muscovadite or granulitic gabbro.
Occurrence.	Outcrop believed to be a sedimentary inclusion in gabbro, southeast of Caribou lake.

(1), Grout, F.F., Petrology and Petrography, McGraw-Hill, 1932, p. 122.

Megascopic.

The rock weathers rusty red, much like the gabbro but on the fresh surface it is dark grey, fine grained, hard, and has the aspect of a quartzite.

Microscopic.

This rock in thin section shows a fine equigranular aggregate of rather rounded anhedral crystals. The texture is hornfelsic, (see pl. 9B). The constituent minerals are plagioclase, olivine, augite, biotite, apatite, magnetite, antigorite, chlorite, iron stain.

The feldspars have the composition of basic andesine, $Ab_{54}An_{46}$. It shows a tendency to assert its outlines against the ferromagnesians. It is slightly altered, to clinozoisite.

The olivine is fairly high in iron being optically negative. It alters to antigorite and much iron oxide. There is almost as much olivine as augite present. The augite occurs in fresh, rounded, non-pleochroic, faintly purple grains.

Biotite and magnetite together form about 10 percent of the rock, the biotite being most often associated with olivine or magnetite. A vein of chlorite cuts the rock.

This rock, although containing no cordierite,

is the same as that named muscovadite by A.N.Winchell, (1). This is believed at Duluth to be a re-crystallized sedimentary inclusion and is very probably the same here.

(1) Broderick, T.M., Titaniferous Iron Ores of Minnesota, Econ. Geology, vol. 12, 1917, pp. 672-673.

EXPLANATION OF PLATE 8.

A. Photomicrograph of aplitic dike (spec. A144:7) showing a quartz crystal surrounding a xenolith of feldspar from the anorthosite.
X 25. Crossed nicols.

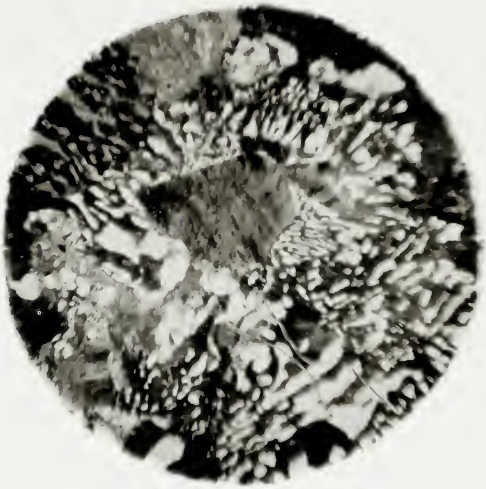
B. Photomicrograph of typical aplitic dike (spec. A144:7) showing altered andesine grains cut by grains and stringers of fresh granophyric quartz and alkali feldspar. The latter in the lower left portion of the plate shows a myrmekitic intergrowth.
X 25. Crossed nicols.

EXPLANATION OF PLATE 8.

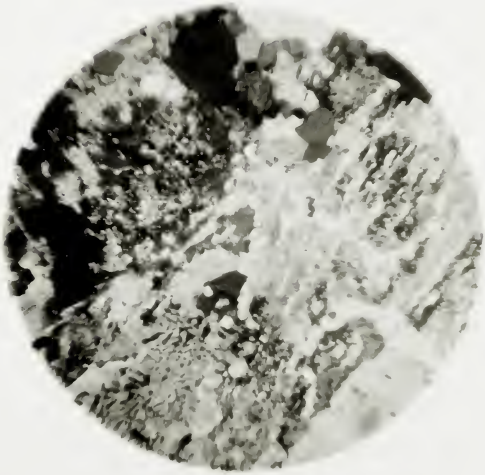
A. Photomicrograph of aplitic dike (spec. A144:7) showing a quartz granophyre surrounding a xenolith of feldspar from the anorthosite.
X 25. Crossed nicols.

B. Photomicrograph of typical aplitic dike (spec. A144:7) showing altered andesine grains cut by grains and stringers of fresh granophyric quartz and alkali feldspar. The latter in the lower left portion of the plate shows a myrmekitic intergrowth.
X 25. Crossed nicols.

PLATE 8



A



B

PLATE 9

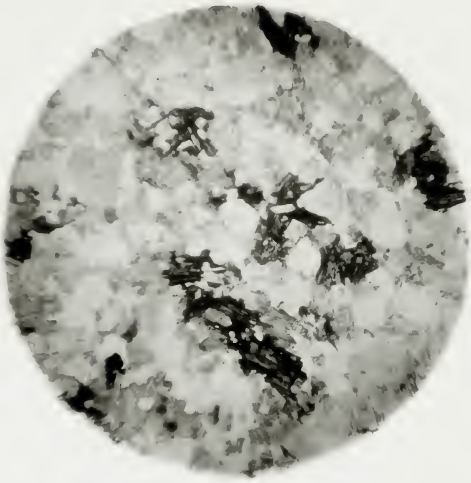
B

EXPLANATION OF PLATE 9

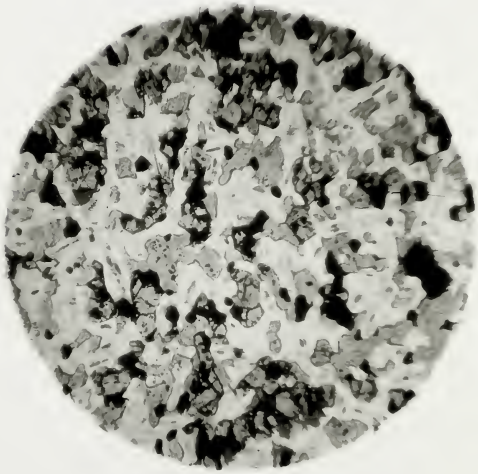
A. Photomicrograph of typical contaminated granite, (spec. F253A) showing clear quartz, clouded oligoclase, and much bleached and chloritized biotite. X25. Ordinary light.

B. Photomicrograph of muscovadite (spec. A144:3). The rock consists of basic andesine, augite, olivine, and magnetite. The texture is hornfelsic. It is considered to be a recrystallized sedimentary rock. X 25. Ordinary light.

PLATE 9



A



B

METAMORPHISM OF THE FRANCOIS RIVER GABBRO

There is little remaining evidence of metamorphism wrought by the gabbro. At one place an outcrop of a dark-grey, fine-grained rock, of quartzitic aspect, appeared to be a recrystallized sediment. In thin section it showed rounded equidimensional grains of plagioclase, olivine, augite, biotite, apatite, and magnetite. The feldspars are basic andesine, $Ab_{54}An_{46}$, The texture is hornfelsic, with an average grain of 1/2 mm., (see pl. 9B). The rock is similar in nearly all respects to that named muscovadite by A.N.Winchell, (1), although it lacks cordierite. In the Duluth mass such a rock is considered to be an entirely recrystallized sedimentary inclusion.

An interesting fact noted in descriptions of the Bushveld is that the first or lowest grade of metamorphism in argillaceous rocks, in which the bedding is still recognizable, is characterized by a development of crystals of chiastolite and like metamorphic minerals. Photographs of the chiastolite show the characteristic regular arrangements of inclusions that might be identically matched in many places in the

(1) Broderick, T.M., Titaniferous Iron Ores of Minnesota, Econ. Geology, vol. 12, 1917, p. 672-673.

metamorphosed sediments in the Francois River district.

The Francois River gabbro is comparatively little altered, considering the batholithic intrusion it has undergone. Gneissic structures due to metamorphism were not noted. The main type of alteration was hydrothermal, attacking most strongly the feldspars of the gabbro and anorthosite. From a macroscopic viewpoint the most evident effects have been a weakening of the rock, producing incoherence, and an alteration of the original grains, shown by dullness of cleavage faces. Microscopically the albite twinning is often obscured by the shreds and fibres of the alteration minerals. Determination of these is difficult owing to the small size of individual grains, but where larger individuals were found, (as in slide A138F), they are largely clinozoisite, and in the more calcic feldspars, calcite. The mafic minerals of the gabbroic rocks are also altered, but minerals lower in the reaction series were formed prior to the development of the commoner alteration products, in the gabbro mostly chlorite. Concurrently the olivine was altered to antigorite.

The more acid rocks within the complex, whether red rock or aplitic dikes, have also suffered hydrothermal alteration. There is apparently an introduction

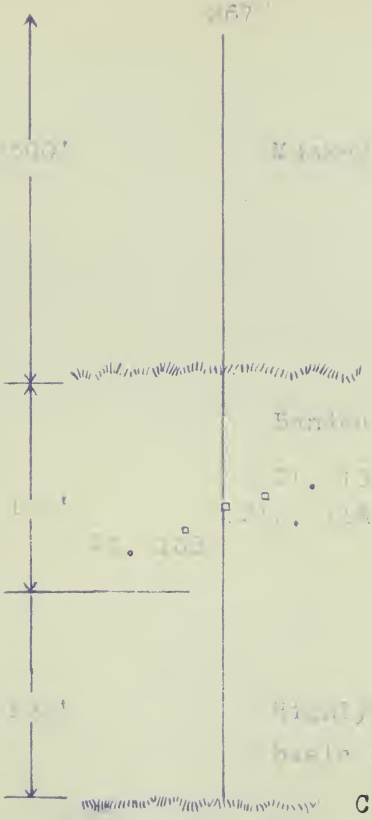
of new quartz and microcline, the old feldspar is sericitized, and in addition clouded with much iron oxide.

The nickel veins contain niccolite and cloanthite-smaltite and other complex cobalt nickel minerals. The gangue mineral is ankerite. The presence of these minerals and of sericite, chlorite, calcite, epidote, serpentine, leucoxene, all combine to suggest that the hydrothermal action may be classed as mesothermal, according to an application of the criteria tabulated in Grout's Petrology and Petrography, (1).

(1) Grout, F.F., Op. cit., p. 427.

STRUCTURE OF THE FRANCOIS RIVER GABBRO

The only definitely primary structure noted in the body was strongly marked banding, which occurs in many places in the gabbro. A description of one of the best exposures of banding, which shows well the degree of differentiation reached, is informative. On the northwest shore of Caribou lake (sta. A138), the succession shown in fig. 1 occurs. The first 125 feet, described as underlain by altered basic rock, is made up of an altered gabbroic rock containing a high percentage of ferromagnesian, which altered to a rusty, yellowish green mineral. One hundred and twenty five feet from the shore of the lake bands of light colored rock up to 8 inches wide appear and become more common until at 175 feet an outcrop of highly differentiated, banded gabbro appears. The banded gabbro continues for a further 75 feet to the cliff edge. Plate 10A shows a particularly striking exposure of banded rock. At this point bands of light and dark colored rock, varying in width from 1/4 to 7 inches, alternate. The bands are made up of plagioclase feldspar, augite and biotite, the dark colored bands, with the higher percentage of ferromagnesian, being rusty weathering where coarse grained. Pegmatitic lenses, the largest of which is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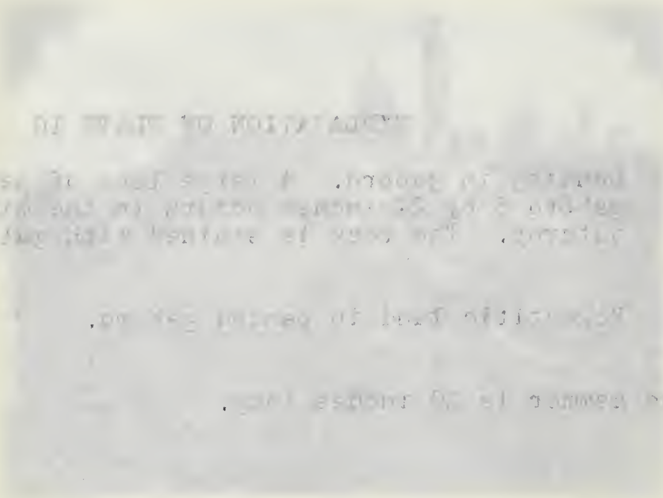
Cliff



EXPLANATION OF PLATE 10

A. Banding in gabbro. A large lens of pegmatitic gabbro 8 by 24 inches occurs in the middle of the outcrop. The rock is stained with gull excrement.

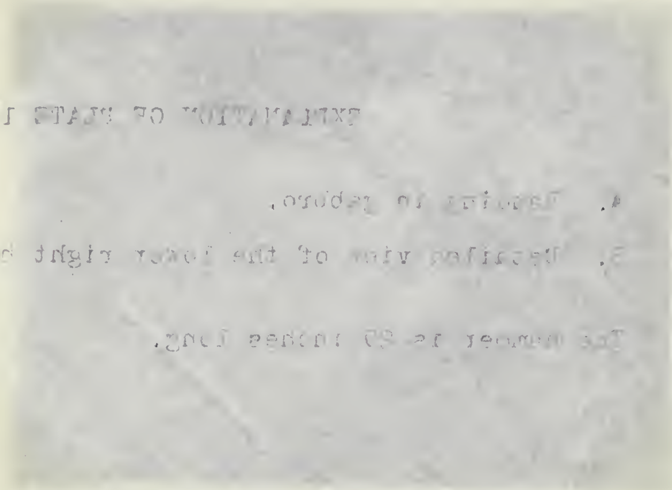
B. Pegmatitic band in banded gabbro.

The hammer is 20 inches long.

PLATE 10

A

B



EXPLANATION OF PLATE 11

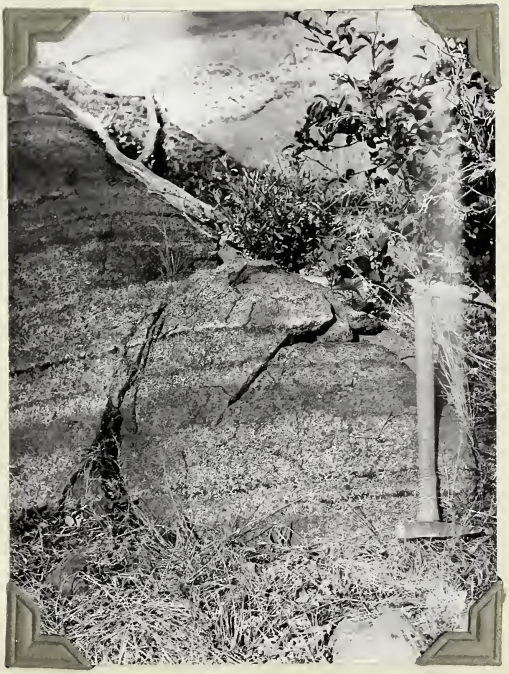
A. Banding in gabbro.

B. Detailed view of the lower right hand end of A.

The hammer is 20 inches long.

PLATE 11

A



B

EXPLANATION OF PLATE 12.

The plate above heading is taken. About 30 feet straight away this the gully cross into a five foot terrette bend.

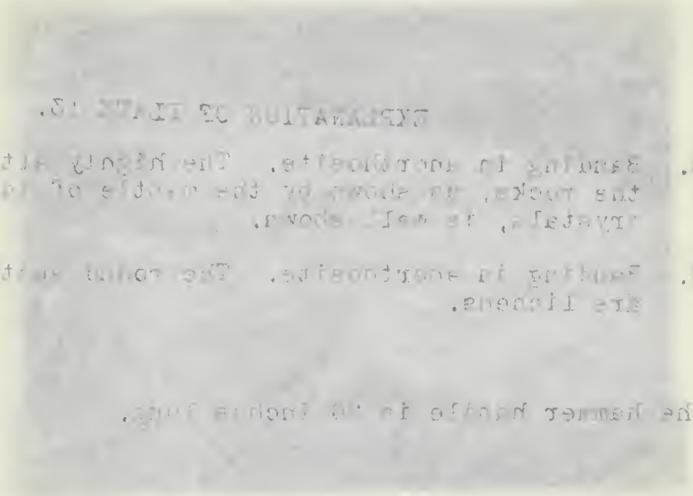
The bam or handle is 30 inches long.

EXPLANATION OF PLATE 12.

The plate shows banding in gabbro. About 50 feet stratigraphically above this the gabbro grades into a five foot magnetite band.

The hammer handle is 20 inches long.

PLATE 12



EXPLANATION OF PLATE 13.

A. Banding in anorthosite. The highly altered nature of the rocks, as shown by the mantle of loose feldspar crystals, is well shown.

B. Banding in anorthosite. The round spots on the rock are lichens.

The hammer handle is 20 inches long.

PLATE 13

A

B

8 by 24 inches, occur in these bands. They contain large augite crystals up to 1 inch in length in a buff to greenish grey matrix of plagioclase feldspar.

About 20 feet south of this outcrop and slightly above it stratigraphically the exposure shown in plate 11A occurs. At the bottom of the section the bands are for the most part light colored, and from 1 to 3 inches thick, separated by somewhat indefinite darker bands. About 1 foot above the bottom a narrow band is very coarse grained. At the top of the outcrop the bands are mainly of the darker colored rock. They are from 5 to 10 inches thick and are separated by lighter colored narrow streaks and lenses, some of which are pegmatitic. The pegmatitic patches in the darker bands consist of crystals of jet black, slightly fibrous hornblende up to 1 inch long, crystals of pink, buff and grey feldspar the same size, and smaller amounts of much altered biotite. No magnetite was apparent and the hornblende seems to be concentrated towards the centres of the patches.

Plate 11B shows thelower right hand portion of this outcrop in greater detail. The bands are of two types, the dark and the light colored bands, both made up of plagioclase feldspar, augite and hornblende

with a little biotite. The dark weathering bands contain about 20 percent more ferromagnesian than the light, and the feldspar tends to weather murky grey instead of chalk white. The grain size averages 1/8 to 1/4 inch, but three pegmatitic bands with crystals up to 3/4 inch in diameter occur. The largest of these has a layer of 3/4 inch feldspar crystals overlying a band of coarsely crystalline ferromagnesians, which in places weather a rusty rose color.

A thick pegmatitic band is shown in plate 10B, taken 25 feet southwest of the preceding plate. This pegmatitic band is 8 inches wide and is made up of extremely coarse (up to 1 1/2 inches) crystals of augite, feldspar and biotite. The band exhibits in places a megalophitic texture, plate 3B showing a hand specimen from this band.

Banded gabbro also occurs north of Mad lake, (sta. F253), Plate 12 shows this outcrop, which about 50 feet stratigraphically above grades into bands of solid magnetite.

The difference between the bands is wholly one of mineral percentages. The lighter weathering bands are higher in feldspar, the darker in ferromagnesian content

but the qualitative mineral composition of each is the same and there is no sharp boundary line between them, the crystals interlocking across the bands.

Orientated specimens of the bands were not collected but in one slide subparallelism of the feldspar laths was noted which suggested that they had settled into position. Banding in the anorthosite is similar to that in the gabbro, i.e., due to variations in percentage mineral composition. Plates 13A & B show banding in anorthosites.

Although there is no agreement as to the actual mechanics of band formation, it is fairly well established that some form of gravitative differentiation is their cause. If this is the case the bands should have originally been horizontal. Collins and Kindle (1) have deduced the structure and subsequent deformation of the Sudbury Nickel Irruptive from this premise in a most convincing manner. In the Francois River body the present dips of the banded rocks therefore show a considerable degree of tilting since consolidation.

In the Bushveld, Duluth, Sudbury, and other

(1) Collins, W.H., and Kindle, E.D., Life history of the Sudbury Nickel Irruptive: II, Intrusion and Deformation, Trans. R.S.Can., 3rd ser., vol. 29, sect. IV, 1935, pp. 27-47.

strongly differentiated basic igneous complexes concordant structure has been amply demonstrated. The Bushveld, Duluth, and Insizwa (1) bodies are all lopoliths. The same structure has been suggested for Sudbury but Collins and Kindle believe it to have been a sill basined by later deformation. The Trout River body (2) is considered by Ingerson to have been a laccolith. It will probably never be easy to deduce the original structure of the Francois River gabbro from such a remnant as it now presents. One can only suggest that it was a concordant intrusion of considerable size.

(1) Insizwa lopolith - Tyrrell, G.W., The Principles of Petrology, 2nd Ed., Methuen, 1930, p.20.

(2) Trout River laccolith - Ingerson, E., Layered Peridotitic Laccoliths of the Trout River area, Am. Jl. Sci., 5th Ser., vol. 29, 1935, pp. 422-440.

AGE OF THE FRANCOIS RIVER GABBRO

Four formational groups have been recognized in the Francois River district, metamorphosed sediments, gabbro, granite, and diabase dikes. The sediments and gabbro are pre-granite in age. This has been established from the following field relationships. At sta. F256 the contact of granite and acid anorthosite was observed. The granite was fine grained near the contact and sent off aplitic dikes into the anorthosite, which showed no change at the contact, being uniformly altered. At sta. F249 pegmatite dikes, evidently derived from the granite, an outcrop of which is 250 feet north, cut the gabbro. Similar relationships were noted at a point 1000 feet east of sta. F258. Between sta. F257 and sta. F258 an outcrop of hybrid granite containing blocks of sediments and of gabbro occurs.

The gabbro is believed to be younger than the sediments which are the oldest rocks in the district. As the gabbro is intrusive, the sediments were probably the intruded rock. At sta. F249 the occurrence of large blocks of bedded sediments included in anorthosite is more conclusive proof of this relationship. The gabbro is then post-sedimentary and pre-granite in age.

Reference should perhaps be made to the fact that practically all the detailed field studies in that part of the Precambrian shield which extends north and west of Rainy lake through Ontario, Manitoba, Saskatchewan, and the Northwest Territories to Great Bear lake have revealed gabbroic intrusives of greater or lesser magnitude, which, insofar as correlations may be drawn between these districts, are of approximately the same age.

COMPARISON OF THE FRANCOIS RIVER GABBRO WITH OTHER SIMILAR BODIES.

The main petrological and structural features of the Francois River gabbro have been outlined above. In such a preliminary study as this, after establishing what appears to be the type into which the body falls, it is illuminating to compare it with similar bodies whose geology is more fully known, and from such comparisons to endeavor to make deductions concerning the body in question. Bodies showing differentiation of the scale of the Francois River gabbro are considered by authorities to be large and such bodies are perhaps more common than is generally realized. Bodies of this type include the Bushveld Igneous Complex, the Insizwa lopolith, the Sudbury Nickel Irruptive, the Stillwater complex of Montana, and the Trout River laccolith of Newfoundland. The Insizwa and Sudbury bodies do not show banding on the scale of the Francois River gabbro, detailed descriptions of the Stillwater complex have not been available to the writer if such exist,(1) and the study of the Trout River laccolith, said to be of this type, is still in the preliminary stages.

(1) Howland, A.L., Peoples, J.W., and Sampson, Edward, The Stillwater Igneous Complex, Misc. Contrib. No. 7, Montana Bureau of Mines and Geology, 1936. (Rec'd Apr 24, 1936)

The Bushveld Igneous Complex.

"The Bushveld Igneous Complex of Transvaal, South Africa,... is a huge, composite body of plutonic and volcanic rocks that outcrops as an irregular oval with a maximum major axis trending east-northeast 288 miles long, and a maximum minor axis 169 miles in length. The total area embraced within the limits of the complex is over 23,000 square miles, but nearly 11,000 miles of this is hidden by a cover of younger strata. The outer, lower part consists of norite, anorthosite, and related basic rocks, and the central upper part of red granite, granophyre, basalt and pyroclastic volcanic rocks.

"The lower part, known as the norite belt, is a huge lopolithic sill that varies in thickness from 1 to 3 1/2 miles and in width of outcrop from 4 to 19 miles. The norite belt has a central sag and dips everywhere about the heart of the complex, at angles between 5 and 50 degrees. In eastern Transvaal it has been subdivided by Hall, into five zones. The Upper Zone, of bronzite norite grading upwards into gabbro and syenite, is approximately 800 feet thick. This merges downward into the Main Zone, which consists largely of bronzite norite, with, near the top, prominent

"bands of magnetite and anorthosite, and has a maximum thickness of about 10,000 feet. Below this is the Critical or Differentiated Zone. It reaches a thickness of 5000 feet in some places, and is so remarkably differentiated into layers of rock of different composition and color that it appears stratified. The rock types include bronzite norite, diallage norite, bronzitite, dunite, chromitite, anorthosite, etc., and some serpentine. Beneath this is the Transition zone -- of bronzite-norite with some layers of pyroxenite -- which is up to 2000 feet in thickness and lies on top of the relatively thin (up to 400 feet) Basal or Chilled Zone of norite.

"The Merensky Horizon is in the upper part of the Differentiated Zone and contains the most important and extensive platinum deposits in South Africa..." (1)

The Duluth Gabbro.

"The Duluth gabbro is a multiple, composite, divided, lopolith. Conservative estimates of its size indicate an area of over 15,000 square miles and a maximum thickness of over 50,000 feet." (2) "It is

(1) O'Neill, J.J. and Gunning, H.C., Platinum and Allied Metal Deposits of Canada, G.S., Can., Ec. Geol. Ser., No. 13, 1934, p. 32.
(2) Grout, F.F., The lopolith, Am. Jl. Sci., 4th Ser., vol. 46, 1918, pp. 516-522.

"estimated that over two thirds of the gabbro mass at Duluth consists of olivine gabbro, varying only slightly from the average. Such average rocks are scattered from top to bottom. On the other hand, specialized types have a more limited range. The peridotite occurs only near the base; the magnetite gabbro, equally heavy, is near the centre; the anorthosite ranges from the centre towards the top and is largely in the thin earlier intrusion. Very locally at the base of the early gabbro there is an apatitic hypersthene gabbro. The occurrence of red rock (is chiefly as) irregular patches at the top of the main gabbro and apophyses into its roof; it occurs also near the top of the earlier feldspathic gabbro, in a large sill close above the gabbro, and in some small dikes near the bottom of the gabbro." (1)

"Banded structure is especially noticeable in the eastern part of the area in which the magnetite bodies occur. In these areas of banded gabbros there are bands of plagioclase-magnetite rock, which, though but a few feet in thickness, extend for about a mile along the strike."(2)

(1) Grout, F.F., A Type of Igneous Differentiation, Journ. Geology, vol. 26, 1918, pp.632, 637.
(2) Broderick, T.M., Op. cit., pp. 666-667.

Conclusions drawn from comparison of the Francois River gabbro with similar bodies.

The Francois River gabbro falls into the same general type as the Bushveld Igneous Complex and the Duluth gabbro. It shows a main rock type very similar to the norite or olivine gabbro of the two bodies. It shows differentiation in the salic-femic direction, anorthosites, rocks so high in mafic minerals as to be almost peridotites, and magnetite-rich rock being found, (1). It shows the same pronounced pseudo-stratification.

Igneous bodies showing a comparable degree of differentiation are all large. Grout, (2), states that bodies which have only differentiated into basic and acid fractions are seldom thinner than 500 feet. Differentiation in the Francois River gabbro, as has been shown, has proceeded much further, being more of the Bushveld or Duluth type. Both these are bodies of great extent and thickness.

In his first paper on the life history of the

(1) Grout, F.F., A Type of Igneous Differentiation, Jour. Geology, vol. 26, 1918, p. 643.
(2) ----------, Petrology and Petrography, McGraw-Hill, 1932, p.253.

Sudbury Nickel Irruptive, W.H.Collins, (1) notes the general likeness of that body to the Bushveld Complex but in remarking on the absence of the igneous banding at Sudbury points out that the Bushveld is much larger. The area of the Sudbury Irruptive is approximately 1000 square miles, and it is approximately 2 miles thick. The area of the Bushveld was 25,000 square miles with a maximum thickness of 15,000 feet, a little less than 3 miles. Therefore it is concluded that the Francois River gabbro must have been considerably larger than at present.

A second important deduction derived from the comparison is that the sequence seems to be, from the bottom up, mafic rocks, highly differentiated gabbro, acid rocks or syenite at the top. This is in general the sequence that would be met with in a traverse across the gabbro from west to east. It is therefore suggested that the body is now inclined, with its top towards the east, but with the whole considerably disturbed by granitic intrusion. A feature corroborating this is the general concordance of the observed strike directions of the banding. When those at sta. A142 and at sta.F253

(1) Collins, W.H., The life history of the Sudbury Nickel Irruptive: I, Petrogenesis, Trans. R.S.Can., 3rd ser., vol. 28, sect. IV, 1934, pp. 123-177.

are neglected, as having been affected by local granitic intrusion, the others all trend approximately north-south, the general structural trend of the country, north of Great Slave lake.

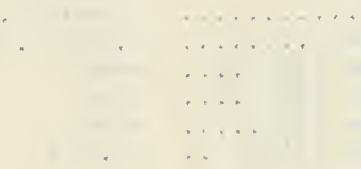
It would require more detailed work to say which of these bodies the Francois River gabbro most resembles. The general scale of its differentiation is more like Duluth than the colossal Bushveld, although in studying the descriptions of both, many phenomena that can be duplicated in the Francois River gabbro were noted.

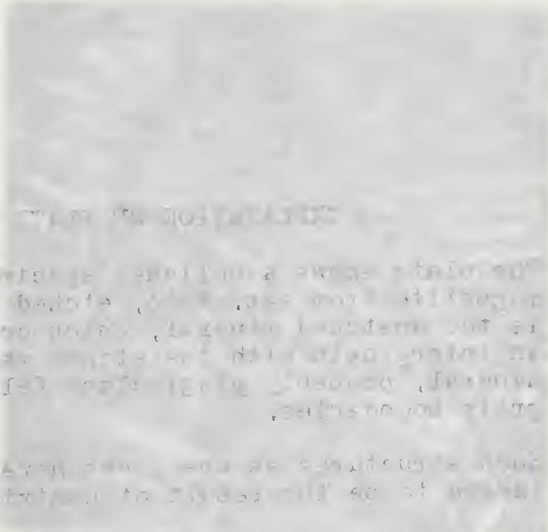
ECONOMIC GEOLOGY.

Metallic Minerals Occurring within the Body.

These may be grouped in two classes, namely, segregations of metallics within the gabbro, and later veins. Reference has been made to the occurrence of metallics as accessory minerals within the gabbro. The occurrence of these as segregations within the gabbro body, constituting a mineral deposit, would be expected from a study of similar bodies, and one segregation of titaniferous magnetite was found.

The magnetite as it occurs in the rock is titaniferous, since it alters to leucoxene and since wet tests indicate the presence of titanium. The pegmatitic patches in the gabbro are often rich in titaniferous magnetite. The band of magnetite at sta. F253 shows a complete transition from an ordinary banded gabbro, (see pl. 12), to a band of magnetite five feet thick. The magnetite crystals are octahedra, up to 1/2 inch in diameter, and seem to possess an octahedral parting. A polished section of the magnetite, (see pls. 14 A & B), showed magnetite intergrown with thin plates or tablets of ilmenite. The ilmenite also occurs in individual grains. The magnetite shows octahedral parting, and the plates of ilmenite parallel the octahedral faces





EXPLANATION OF PLATE 14.

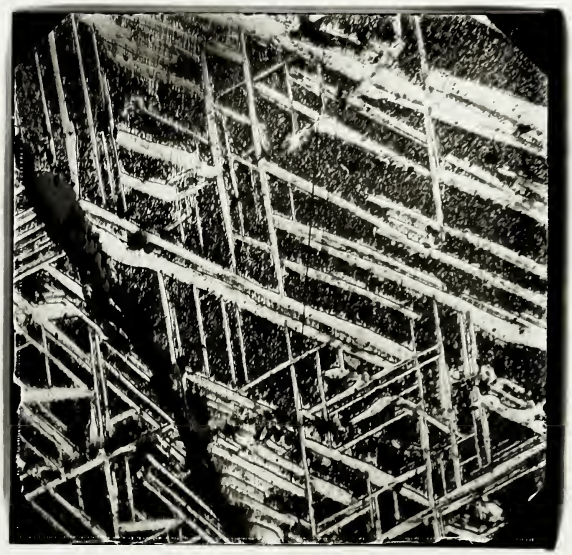
The plate shows a polished specimen of the titaniferous magnetite from sat. F253, etched with HCl. The ilmenite is the unetched mineral, which occurs in grains and as an intergrowth with the etched magnetite. Silicate mineral, probably plagioclase feldspar occurs along the grain boundaries.

Such structures as are shown here, are in metallurgy considered to be the result of unmixing.

Pl. 14A is magnified 100X, plate 14B 250X.

PLATE 14

A



B

The presence of gold in titaniferous magnetite has apparently not been previously noted. The explanation may be that the intrusive hybrid granite in contact with the band, which carries pyrite, may have introduced the gold.

Possibility of Platinum, Chromite and Nickel Segregations in the body.

This possibility must occur to everyone with even a cursory acquaintance with the Bushveld Complex, which contains these metals, none occurring stratigraphically near the magnetite. On the other hand, the Duluth gabbro contains only deposits of titaniferous magnetite. The difference is apparently due to the fact that in the one case the magma contained appreciable quantities of platinum, chromium, and nickel, and in the other it did not. Whether the Francois River gabbro contains such deposits depends on whether or not its magma contained these elements. This may only be determined by careful prospecting, which would be fully justified by the possibility of finding such deposits.

Nickel Occurrences.

The discovery of two veins of nickel and cobalt minerals within it first led geologists to the gabbro body. These veins occur midway between Caribou and Great Slave Lakes. They have been described by C.H. Stockwell, (1), who classed the gabbro as augite diorite. The veins strike about N80°E, and parallel a rather well marked jointing in the granite. They cut granite dikes, cut, and therefore are younger than, the gabbro.

The veins contain botryoidal masses of niccolite surrounded by cobalt-nickel-arsenic minerals including cloanthite-smaltite and gersdorffite? (2). Cloanthite-smaltite also occurs alone. The gangue mineral is ankerite. At the widest point the veins are not more than 15 inches across and the one carrying the highest mineral content has only been traced for 230 feet. A chip sample taken by Stockwell showed only a trace of gold and 1.97 oz. of silver. Evidently, unless further prospecting develops larger bodies of nickel, or higher precious metal content, they are of no value at present.

(1) Stockwell, C.H., Op. cit., pp. 55c and 60-61c.
(2) Cameron, A.E., Oral communication.

SUMMARY

OF CONCLUSIONS DERIVED FROM THIS STUDY.

This thesis presents the results of a field and laboratory study of a body of gabbro-like rocks which occur near the Francois river, on the north shore of Great Slave lake. This body, whose exposed surface is 13 square miles in area, was nevertheless found to present an example of extreme differentiation comparable to the Bushveld Igneous Complex or the Duluth gabbro.

The rocks occurring in the district are of three main types, metamorphosed sediments, gabbroic rocks and granitic rocks, in order of age, i.e., the gabbro body intruded the sediments, and was intruded by the granite.

The gabbro-like rocks may be divided into two broad groups, gabbros and anorthosites. Other monomineralic differentiates noted were a banded segregation of magnetite, and two subordinate masses of ultrabasic rock. The masses of ultrabasic appear to be amphibolites. Neither is within the gabbro and as one is an island and the other is a hill whose sides are covered with drift their relationships were not determined.

The gabbros include rocks whose ferromagnesians

are olivine, augite, and hornblende. The feldspars are plagioclase, ranging in composition from basic labradorite to acid bytownite. The sequence of crystallization was feldspar, olivine, magnetite and/or augite. As a consequence many of the rocks show ophitic texture, and for those which show ophitic texture in the hand specimen, the textural term "megalophitic" texture was coined. The grain size of the gabbro varies from medium to coarsely pegmatitic, the latter phase representing concentrations of mineralizers along bands and in irregular areas in the rock.

The anorthosites have approximately the same qualitative mineral composition as the gabbros, but are more altered, and thus the interstitial grains of ferromagnesian mineral are too altered to determine. An interesting feature is a gradation from normal to acidic anorthosite, the feldspar of the latter being basic oligoclase.

These rocks have been hydrothermally altered and the feldspars are filled with shreds and patches of calcite. The ferromagnesians have altered to epidote and chlorite. The rocks contain well developed reaction rims, which show the reaction series of Bowen, and the related synantectic phenomena. It was not possible to determine whether the reaction rims were

due to primary magmatic reaction or secondary reactions.

The gabbros are cut by many aplitic dikes. These show two generations of feldspar, altered andesine and fresh microcline and oligoclase, the two last named minerals occuring along with quartz as stringers and granophyric aggregates in the altered feldspar. The mass of evidence suggests that they are aplitic dikes, genetically connected with the granite, along which later magmatic action has taken place. Another manifestation of hydrothermal action is the nickel-cobalt veins which are genetically connected with the granite as well.

The gabbro body shows strongly marked primary banding. Light and dark weathering, and medium grained and pegmatitic bands alternate in many places in both gabbro and anorthosite. At one place the gabbro passes into a five foot band of titaniferous magnetite, which microscopic examination shows is an intergrowth of ilmenite along the octahedral faces of the magnetite.

Comparison with similar highly differentiated basic bodies leads one to the conclusions that the gabbro body was originally a much larger body than at present, that it was a concordant intrusion which has now been tilted so that it strikes approximately north-south with an eastward dip, and that there are possib-

ilities of platinum, chromium, and nickel deposits occurring in the Francois River gabbro.

BIBLIOGRAPHY

This bibliography includes only the more relevant works referred to in the preparation of this thesis. Many of the papers cited contain full bibliographies on their particular field.

Bowen, N.L., The Evolution of the Igneous Rocks, Princeton University Press, 1928.

Broderick, T.M., The Relation of the Titaniferous Magnetites of Northeastern Minnesota to the Duluth Gabbro, Econ. Geology, vol. 12, 1917, pp. 663 - 696.

Collins, W.H., The Life History of the Sudbury Nickel Irruptive, I, Petrogenesis, Trans. Roy. Soc. Canada, vol. 28, sect. IV, 1934, pp. 123-127.

Collins, W.H. and Kindle, E.D., The Life History of the Sudbury Nickel Irruptive, II, Intrusion and Deformation, Trans. Roy. Soc. Canada, vol. 29, sect. IV, 1935, pp. 27 - 47.

Daly, R.A., Igneous Rocks and the Depths of the Earth, McGraw-Hill, 1933.
(Contains a list of bodies showing gravitative differentiation in concordant intrusions.)

Gillson, J.L., Granodiorites of the Pend Oreille District of Northern Idaho, Jour. Geology, vol. 35, 1927, pp. 1 - 31.

Gillson, J.L., Callahan, W.H., and Millar, W.B., Adirondack Studies: The Age of Certain of the Adirondack Gabbros and the Origin of the Reaction Rims and Peculiar Border Phases Found in them. Jour. Geology, vol. 36, 1928, pp. 149-163.

Grout, F.F., The lopolith, Am. Jl. Sci., 4th Ser., vol. 46, 1918, pp. 516 - 522.

----------, Internal Structures of Igneous Rocks, Jour. Geol., vol. 26, 1918, pp. 439-458.

----------, A Type of Igneous Differentiation, Jour. Geol., vol. 26, 1918, pp. 628-658.

----------, The Pegmatites of the Duluth Gabbro, Econ. Geology, vol. 13, 1918, pp. 185-197.

----------, Petrology and Petrography, McGraw-Hill, 1932.

Hall, A.L., The Bushveld Igneous Complex of the Central Transvaal, Geol. Surv. of South Africa, Mem. 28, 1932.

Hills, E.S., An Unusual Occurrence of Myrmekite and its Significance, Geol. Mag., vol. 70, 1933, pp. 294-301.

Ingerson, E., Layered Peridotitic Laccoliths of the Trout River District, Newfouldland, Am. Jl. Sci., 5 th ser., vol. 29, 1935, pp. 422-440.

Jolliffe, F., Preliminary Report, Yellowknife River Area, N.W.T., Geol. Surv., Can., paper 36-5, 1936.

Mawdsley, J.B., St. Urbain area, Charlevoix district, Quebec, Mem. 152, Geol. Surv., Can., 1927.

O'Neill, J.J., and Gunning, H.C., Platinum and Allied Metal Deposits of Canada, Geol. Surv., Can., Econ. Geol. Ser. No. 13, 1934.

Osborne, F.F., Certain Magmatic Titaniferous Ores and Their Origin, Econ. Geol., vol. 23, 1928, pp. 724-761, 895-922.

Schwartz, G.M., The Relations of Magnetite and Ilmenite in the Magnetite Deposits of the Duluth Gabbro, Am. Min., vol. 15, 1930, pp. 243-252. (Contains bibliography of titaniferous magnetites)

Sederholm, J.J., On Synantectic Minerals, Bull. Comm. Geol. de Finlande, N:o 48, 1916.

Stockwell, C.H., Great Slave Lake-Coppermine River area, Geol. Surv., Can., Sum. Rept., 1932, part C, pp. 37c-63c.

Tyrrell, G.W., The Principles of Petrology, 2nd Ed., Methuen, 1932.

GEOLOGICAL MAP OF FRANCOIS RIVER DISTRICT N.W.T.

SCALE: 1" = 1 MILE

1 0 1 2 3

LEGEND

- Granite
- Gabbro, etc
- Met Sediments
- Station
- Strike of banding
- Centre of aerial photograph

BIRD LAKE
WHITE MAN L
MAD L
CARIBOU LAKE
Paul Lake
Trout Lake
FRANCOIS RIVER
FRANCOIS BAY
GREAT SLAVE LAKE
Nickel veins
40R
41R
37R
32R
32C
31C
37C
38C
39C
40C
38°

Map prepared from R.C.A.F photographs
by A.F Buckham
Geology by A.F Buckham under direction of
Dr. F. Jolliffe, G.S of Canada.